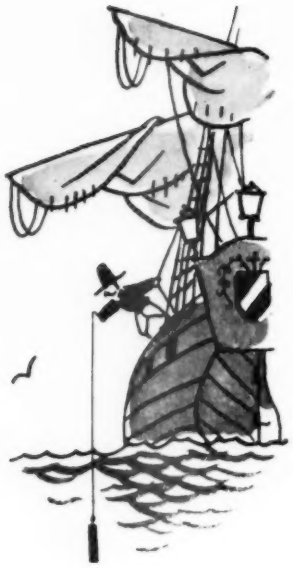
JOURNAL OF

Petroleum Technology

MAY, 1952



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Official Publication of the
PETROLEUM BRANCH
American Institute of Mining and Metallurgical Engineers, Inc.
408 Trinity Universal Building
Dallas, Texas

Statements and opinions contained in the JOURNAL OF PETROLEUM TECHNOLOGY are, unless otherwise indicated, attributable only to the author, and do not necessarily reflect the views of the AIME, its officers, committees, or other agencies.

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Journal of Petroleum Technology

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TABLE OF CONTENTS

Editorial Features — Section 1

Editorial: Now Is the Time to Choose Engineering, by William B. Plank 11
Management Looks at the Engineer, by Carl E. Reistle, Jr. 13
Education for Engineering, by Arthur F. Taggart . . 15
Opportunities in Engineering and Science, by Carey H. Brown 17
Characterizing Features of the Petroleum Engineer, by Harry H. Power 19
Evaluating a Petroleum Engineering Curriculum, by Holbrook G. Botset 23
Staff Problems Relating to Engineering Education, by Charles F. Weinaug 25

Petroleum Transactions

Behavior of Dissolved Oxygen in Oil Field Brine, by George G. Bernard and Glenn A. Marsh 119
The Delta-Log, a Differential Temperature Surveying Method, by R. B. Basham and C. W. Macune . . . 123
Observations from Profile Logs of Water Injection Wells, by H. H. Kaveler and Z. Z. Hunter 129
Prediction of Saturation Pressures for Condensate-Gas and Volatile-Oil Mixtures, by E. I. Organick and B. H. Golding 135

Institute Affairs — Section 2

Drift of Things, by Edward H. Robie 1
Petroleum Branch Affairs, by Joe B. Alford 1
Executive Committee Meeting, by Jess E. Adkins . . 2
Personals 5
Employment Notices 6
Petroleum Branch Membership 6
Book Reviews 8
Advertisers' Index 8

On the Cover — This month's cover depicts a Pennsylvania State College student measuring the compressibility of reservoir rock in a laboratory test. It is a typical activity of engineering students all over the country and is in line with this issue's dedication to engineering education and the seriousness of the present shortage of engineers. — *Photo courtesy Pennsylvania State College.*

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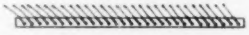

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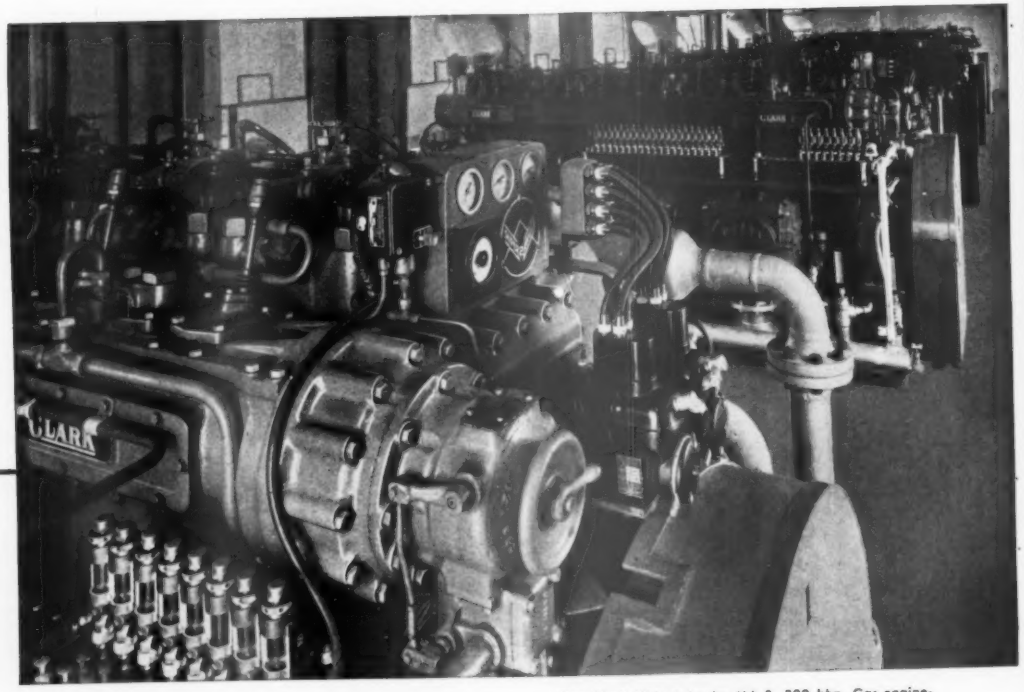
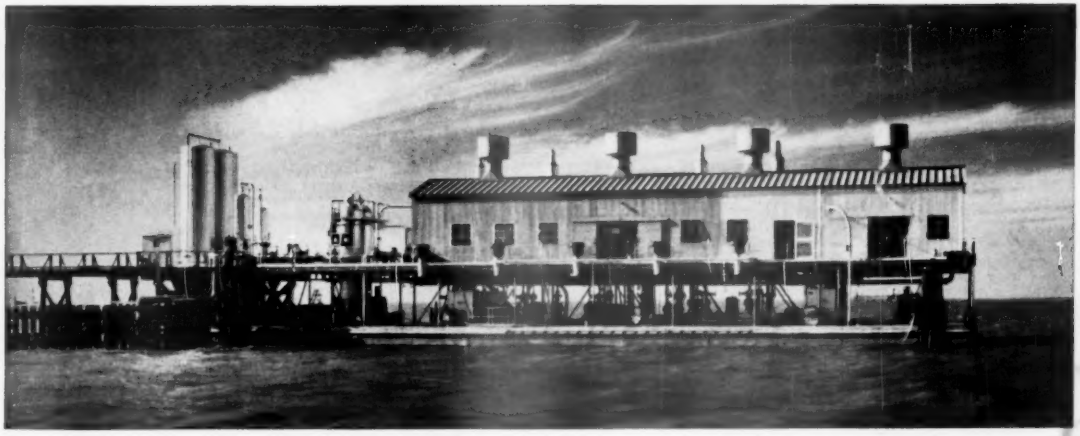


Five Clark Midget Angle, MA-8, 300 bhp, Gas-engine-driven Compressors in new compressor barge operated by Gulf Oil Corporation off coast of Louisiana



fill this tough Oil's new compressor barge

In Grand Bay, five miles off Louisiana's shores, lies Gulf Oil Corporation's new compressor barge. This floating compressor station, and two others soon to be placed in service, will eliminate gas flaring in five separate Louisiana fields, with the gas being pumped into transmission lines.

The five Clark Midget Angle Compressors aboard represent fulfillment of one of the toughest compressor assignments imaginable. The barge had to be designed to ride out hurricanes, and it was expected that heavy seas would keep its deck awash during these periods of bad weather. This meant that the compressors had to be mounted on steel framework high above deck. The perfect balance of Clark Midget Angles made this feasible and five Clark MA-8, 300 bhp, gas-engine-driven compressors were installed — Gulf Oil's assurance of vibrationless performance.

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Dual completions of the past quite often utilized steel body type packers which were not too well suited to certain installations, were subject to corrosion and attack by deleterious well fluids, and were difficult to mill out in case of emergency, or when subsequent operations necessitated their removal.

When planning a dual completion today, a good starting point is to think of the Baker Retainer Production Packer which eliminates the above objectionable features.

All major parts of this packer are made of gray cast iron which is *far more resistant to corrosion and embrittlement than steel*—and yet can be *drilled up readily* (not milled) when desired. The oil-resistant, temperature-resistant packing element is held in position by lead sealing rings, and provides a leakproof seal which *prevents movement* of fluid or gas *either up or down the hole*. Two sets of opposing slips hold the packer assembly at setting point regardless of differential pressures, set-down weight, tubing expansion or contraction.

The Baker Retainer Production Packer is truly revolutionary because, when set, it *virtually becomes a part of the casing*, leaving the tubing string *free for running in* or for *removal from the well*, meanwhile maintaining complete isolation of the producing zones.

The Baker Retainer Production Packer can be set safely and accurately on tubing or drill pipe, but to save wear and tear on precious tubular goods, we recommend setting on an electrical conductor cable by one of the leading wire line service organizations. After reviewing the two dual completion installations on the opposite page, we suggest that you contact the nearest Baker representative for helpful, profitable recommendations. —Then, by selecting the required Baker Packer Accessory Equipment, your specific "dual zone" or single-zone production requirements will be readily met.

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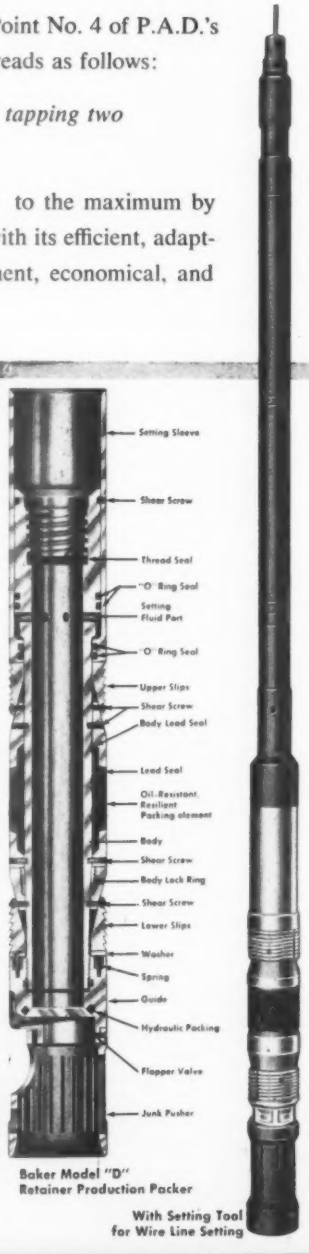

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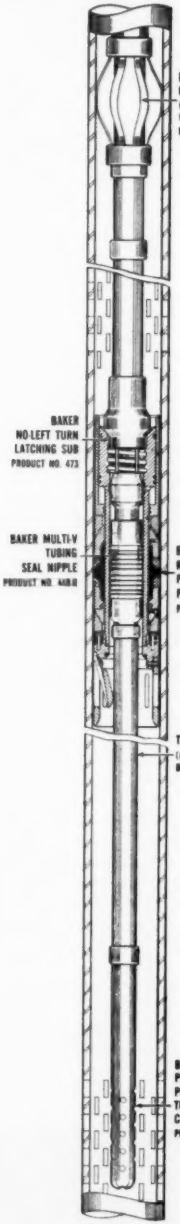
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HERE ARE A COUPLE OF GOOD EXAMPLES OF MODERN DUAL COMPLETION INSTALLATIONS...

LEFT—This *one-packer* hook-up provides a means of producing two zones at the same time, the *lower* zone being produced through the tubing, and the *upper* zone through the annulus between the tubing and the casing. Such a dual-zone installation is used where:

1. It is necessary to *pump* the *lower* zone. The tubing may be anchored to the packer to prevent movement of the tubing during the pumping cycle which will allow for increased plunger travel.

2. With both zones flowing, the differential pressure across the packer (from below) is greater than 2000 psi.

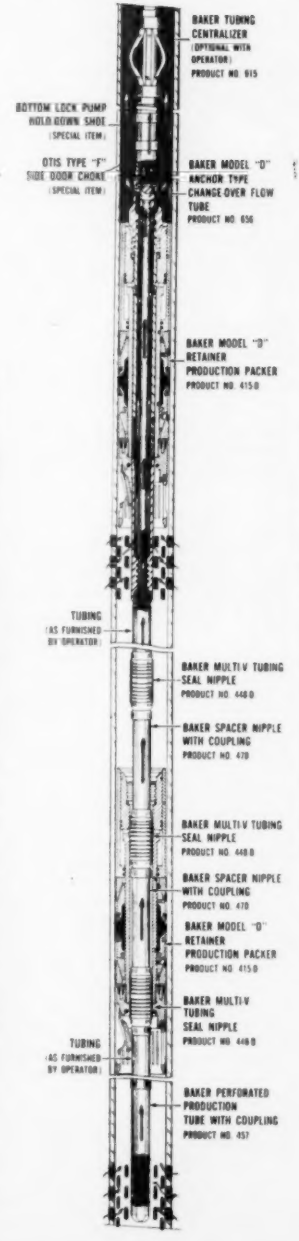
3. It is necessary to produce the *lower* zone, and inject water or gas from the surface into the *upper* zone.

4. The *upper* zone is produced through the annulus between the tubing and the casing, while water or gas is pumped down the tubing into the *lower* zone.

RIGHT—This dual-zone hook-up is designed primarily to permit *pumping* the *upper* zone and *flowing* the *lower* zone. Two Baker Retainer Production Packers, an Anchor-Type Change-Over Flow Tube and other Accessory Equipment are required. The *lower* packer is set *just below* the *upper* zone in order to prevent an excessive amount of sand from settling on top of the packer. The *upper* packer is set immediately above the *upper* zone, and continuous isolation of the zones is maintained.

The tubing string is held in tension for efficient pumping; the pump can be pulled for re-placement of parts, the *lower* zone meanwhile remaining isolated; provision is made for washing out sand or settlings to facilitate removal of the production string. In fact, nothing is lacking to provide flexibility of operation, combined with efficient, low-cost, permanent, dual-zone production.

The new, 84-page Baker Packer Brochure contains many other interesting installations, and will be sent to any oil man upon request. Or see your nearest Baker representative for specific recommendations.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Guest Editorial

Now Is the Time to Choose Engineering

By William B. Plank

Head, Department of Mining and Metallurgical Engineering
Lafayette College

THE FIGURES on engineering enrollment for the current year in the schools of the United States and Canada released jointly by the U. S. office of Education and the American Society for Engineering Education, vividly emphasize the critical dearth in the supply of engineers of all kinds at a time when their services are most seriously needed by vital industries in both countries. This study of the situation is an analysis of these figures with a segregation of the mineral engineering data and with comparisons of the data for the years 1944-45 to date. The most recent previous study was printed in *Mining Engineering* for August, 1951.

There are 19 per cent fewer undergraduate and graduate mineral engineering students enrolled in the E.C.P.D. accredited schools of the United States this year than a year ago. The figures are: 8,727 this year and 10,674 last year.

The entire engineering group in both countries numbers 171,070, as compared with 184,547 last year and 252,250 in 1947-48, the peak year. This is a decrease of 7.3 per cent since last year, less than half the decrease in the mineral engineering group.

The seriousness of the situation is shown by the fact that there is a reported demand for from 60,000 to 90,000 engineers this year by the civilian and defense industries, and to meet this demand it is expected that only 35,800 will graduate next month. To make the matter worse, many of the 1952 graduates are subject to the Selective Service, having been granted deferments while they were in college, and accordingly industry is likely to find itself with a deficit of from 40,000 to 60,000 engineers.

The shrinkage in the number of engineers receiving their bachelor degrees in the United States and Canada, that began with last year's graduating class, will continue, according to some authorities, until 1960. From the numbers in the classes now in the schools we can at least foresee that the curve of graduates will continue to decline until June, 1955, when the present freshman class of 40,913 will graduate. But, of this number, we can expect not more than 20,000 to finish their college work. The trend of graduates beyond 1955 will, of course, depend upon the size of the entering classes. It is not expected that they will reach the normal pre-war rising curve until after 1960.

The number of mineral engineering graduates that will be available from the United States schools next June is estimated to be 2,317. This is arrived at by adding to the number of seniors those that are in the fifth year of the five-year programs. They are as follows: mining engineers 434, metallurgical engineers 646, petroleum engineers 753, ceramic engineers 196, and geological engineers 288. Prospective employers of these men would be well advised to contact them early. In fact the personnel representatives of many companies are already in the process of doing just that.

Many agencies have been publicizing to young men of college age the unusual opportunities that exist today in all engineering fields. It is evident from this study that the greatest needs are in the mineral engineering fields where there is the least crowding and where the opportunities for satisfactory careers are more numerous today than ever before in our country's history. Each and every member of this division would be rendering a great service to his country and to the young men of his acquaintance if he would make these facts known wherever and whenever possible.

Young men with engineering aptitudes should be advised to consider training for a career in mineral engineering offered by 63 mineral engineering schools in the United States and eight schools in Canada. A directory of these schools will be supplied by the American Institute of Mining and Metallurgical Engineers, 29 West 39th Street, New York 18, New York. ★ ★ ★

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Management Looks At the Engineer

By Carl E. Reistle, Jr., Member AIME
Production Director
Humble Oil and Refining Co.

What does management want in an engineer? Among other things, the author claims, it wants a well-trained mind and character. Without being a back-slapper, he must also have "personality" and an ability for oral and written expression.

AN engineer is a man who stands between pure science and practical application. He takes the theoretical and converts it into the useful. To a large extent, therefore, the engineer's place in any particular industry can usually be described in the rigid terms of a job classification. But management must look for more than a bare skeleton which fits a particular job classification. It wants meat on the bones.

That requires, first of all, a sound educational background. Now, there has been quite a hullabaloo over the years as to just what constitutes a good education in engineering. One school of thought has long held that the engineer should be trained to fill a specific need in a narrow industrial field. Looking back 10 years, for instance, we find one college graduating 18 different varieties of mechanical engineers alone. But is increased specialization the answer? The preponderance of opinion has gradually been shifting toward the second alternative.

Today a large segment of industrial management holds to the conviction that the engineer needs more intensified training in those sciences for which he is going to act as a catalyst, who takes scientific information and, by acting on it, reduces it to practice. Referring to our own industry, P. H. Bohart puts it this way: "It is impossible to foresee the ultimate niche into which each petroleum engineering graduate will fit himself. It seems apparent, therefore, that the emphasis must be placed on fundamentals and that the student must receive as broad a course as possible so that he will find himself reasonably well equipped wherever he may start and wherever fate and his particular talents may take him... It is not necessary that a graduate petroleum engineer know what a sucker rod is but it is necessary that he know something about thread design and stresses, and something about iron and steel alloys."

This is not to say the industry has small need for specialists. Obviously this modern world is growing more specialized, not less. But as Dr. William V. Houston, president of the Rice Institute, has said: "Much of the art of engineering must be learned on the job. Experience cannot be entirely replaced by any training, no matter how good."

Techniques and operating conditions can change fast in modern industry. When that happens, it is the man well versed in the fundamental sciences who can change with them. A pertinent example is that phase of the petroleum industry known as reservoir engineering, a development of just the last 20 years. Our chemical engineers, we have found, have been particularly successful in this new field, not because they are a whiz in the laboratory but because, generally speaking, they have a superior foundation in the natural and engineering sciences.

Paper presented at the Petroleum Engineering Management Conference, sponsored by the School of Petroleum Engineering, University of Oklahoma, Norman, Okla., March 15-16, 1952.

Five-Year Program

Obviously specialization cannot be completely ruled out of the college curriculum — nor need it be. Adding another year to the conventional four-year course, or setting up more post-graduate schools for engineering specialists, would seem to be the solution. This would also permit filling in other much discussed educational gaps such as those in economic subjects and the humanities. The professional engineer will always face the problem of communicating his conclusions and his recommendations to management. Lack of proficiency in the making of written and oral reports and in economics, business, and the humanities are gaps responsible for retarding the progress of many an engineer.

A sound educational background, then, is one thing management looks for in the engineer. But formal education is not everything. Some of our greatest discoveries have been made by men who never went to college except to receive an honorary degree, and some other very fine engineers never stayed in school long enough to collect a sheepskin. The professors of George Westinghouse, for example, took such a dim view of his scholarly attainments that they booted him out of Union College after a three-months stay. Not at all fazed by this adverse appraisal of his abilties, young Mr. Westinghouse proceeded to invent the air brake before his 21st birthday.

In its infancy, the oil industry saw many a latterday Westinghouse come up with worthwhile tools or techniques. Even now the story is often repeated. My own company has what it calls a "Coin-Your-Ideas" program, and hardly a month goes by that some toolpusher or driller doesn't send in an excellent method for doing a petroleum engineering job faster, safer, and more economically.

What else does management expect in a prospective addition to its engineering staff? It is here that we come to some of the intangibles and the imponderables — to characteristics of mind, of character, and of personality which are tremendously important albeit elusive of scientific definition.

On this and the following pages, a member of top management takes a look at prospective engineers and expresses management's views on what it wants in an engineer. On subsequent pages, prominent educators give their views on what industry should look for.

Intangible Requisites

First of all, an engineer must have a well-trained mind — a mind in which there is no place for the slipshod. Since his life, to borrow an old phrase, is likely to be just one problem after another, he must be able to see these problems clearly and to think them through. He must be able to separate truth from opinion, and opinion from guess. Only then can he take intelligent action on the problems at hand.

He should also have an adaptable mind. A great heritage of knowledge and technique has been handed down to the engineer, and his mental makeup should be one which spurs him to adapt this heritage to practical uses both new and old. On a large scale, this trait was an indispensable factor in building the atomic bomb. Here was a tremendous example of adaptability.

The second broad trait that management expects to find in the engineer is character. It has been said that "even in the daily walks of business there is frequent temptation to obscure the truth." Engineering is no exception to the rule, but there is absolutely no place in the profression for the man who succumbs to that temptation. The engineer's professional character should be like that of Caesar's wife — above suspicion.

In its dictionary sense, character stands for a sense of moral vigor and firmness such as is acquired through self-discipline. There are other facets to the trait, however, and these might be said to range all the way from ambition to serve to willingness to cooperate. The kind of character management hopes to find in the engineer includes such things as initiative — a deep desire to reduce his knowledge of science to practice; persistence — the quality of seeing the job through no matter what the obstacles; fairness and honesty in all his dealings; and loyalty to both the policies of his company and the principles upon which this country was founded.

A good indication of the engineer's character may be found in his attitude toward his profession — in the respect he has for it. If a man doesn't respect himself and his job, he can't expect such respect from others. And not until this respect is forthcoming can he win the confidence of capital and the entrepreneur — something he must have if he is to function as an engineer. Not until then can he sell his ideas.

Personality — the social traits of the engineer — should be added to mind and character as the third broad quality in which management is very much interested. A good personality is a definite asset, but implied here is not so much the back-slapping or glad-handing of the hail-fellow-well-met as is the ability to work in harmony with one's associates. This ability, in short, constitutes what today is widely known as human relations. Only the name, however, is new. Successful men have practiced good human relations since the dawn of our industrial era.

The Human Equation

Good human relations simply means the engineer should be fully aware that reducing science to practice involves the use of human beings; that in any engineering solution to a problem, one of the symbols must be a human relations symbol. A project which works out wonderfully well on the drawing board can fall apart like a house of cards if the human equation is left out.

H. G. Batcheller, president of Allegheny Ludlum Steel Corp., has pointed out that this is often quite difficult for the engineer to do since he has been schooled to eliminate the human factor. But he goes on to say: "The engineer must know not only his table of stresses and strains, the melting points of copper and steel, but also the boiling point of human tempers. And he should appreciate that it is as important to take the squawks out of people with a little praise and encouragement as it is to take the squeaks out of motors with a little oil."

But even though he has the finest of educational backgrounds and the most alert and adaptable of minds, even though he has an unimpeachable character and the warm personality of a Will Rogers, the engineer will never find his life a bed of roses. In his autobiography, Herbert Hoover took time out to elaborate on this point:

"The great liability of the engineer," Hoover said, "compared to men of other professions, is that his works are out in the open where all can see them. His acts, step by step, are in hard substance. He cannot bury his mistakes in the grave like the doctors. He cannot argue them into thin air or blame the judge like the lawyers. He cannot, like the architects, cover his failures with trees and vines. He cannot, like the politicians, screen his shortcomings by blaming his opponents and hope that the people will forget. The engineer simply cannot deny that he did it. If his works do not work, he is damned."

Hoover's observations still hold true. They still hold true even though we now have a seller's market in engineering and even though it now looks as if for several years more engineering students will be rivaling football stars in both campus prestige and numerical scarcity. But that does not mean the individual engineer can afford to lower his standards. He may be able to take his choice of jobs today, but throughout his subsequent career, management will be putting to his work the sharp pencil of economics and the yardstick of achievement.

The Engineer's Decision

For the engineer who can meet the requirements of modern industry, for the man who can accept and carry responsibility, there will always be great rewards — rewards both in the material things of life and in the spiritual satisfaction that comes from creative endeavor. And there will be no dead ends to his career. He can move as far as his abilities and his personal qualities will carry him — and this often means into the ranks of top management. But whether he accepts the responsibility of management or elects to remain an engineer must depend on the person himself. There are men — Kettering is an example — whose basic challenge is to continue as an engineer. Somewhere down the line each engineer must analyze his own ability and decide whether he wants to work through people as a manager or stick to reducing theories to practical use.

The important thing is for the engineer to find his own place in society — to find the place where his peculiar talents can accomplish the greatest good. His recompense will be not only in monetary returns but also in the more soul-satisfying rewards of universal respect and admiration.

Another observation from Hoover's life story is: "Our preoccupation in America with the common man," he says, "must not let us forget that our advancement depends on the uncommon man."

Because of the nature of his work, the engineer must forever remain among the uncommon man. His problems, his duties, his responsibilties will be uncommon, too. But if he can live up to the letter and spirit of his profession, the engineer's place in civilized society will always be an honorable one — and he shall have played the vital role of catalyst in making this world a better place in which to live. ★ ★ ★

Education for Engineering

By Arthur F. Taggart
Professor of Mineral Engineering
Columbia University

The author lists six basic engineering studies and then adds a seventh element, man himself, with which the engineer should acquaint himself. Not until he has comprehended all, and the human factor, can he call himself an engineer.

LET me start this detailed discussion of education for engineering in orderly fashion with a definition of engineering: Engineering is the direction of profit-seeking control of the phenomena of inanimate nature.

Disregarding the words "profit-seeking," we are left with "direction," "control" and "natural phenomena" as foci of interest in the training of engineers.

Chemistry and physics comprise the basic record of all that is known in definite and certainly determinate form about natural phenomena. Mathematics is the tool of coordination and quantification of these facts. Control of the phenomena requires *working* knowledge of them. Hence, thorough study of these three subjects is one of the major parts of engineering education.

Each of these subjects comprises a field too large to be mastered by any one man. Yet the engineer should be able to go into each, or all three, for solution of a given technical problem. The answer to the dilemma is a matter of teaching.

At any given moment substantially all that is known about these subjects is in print. The great bulk of it is summarized in books. Hence, training for self-study of the books at an economical rate should be the aim of instruction. This can be accomplished, as far as it is possible in four years, by continuing the study of all three subjects throughout the undergraduate term, and by concentrating in the teaching, by everlasting repetition, on the truly basic concepts, preferably by a multitude of problems.

Engineering's Six Studies

Basic engineering studies, as I define them, comprise the generalizations about materials and energy and their coactions that have not yet reached the standards of definiteness and certitude of knowledge that would give them rank as sciences. I classify them into six subjects:

Materials
Stationary Structures
Energy Transformation
Machines
Process Elements
Approximation

No engineer can divorce himself, without loss to his effectiveness and reputation, from responsibility for the capacity to attack problems in all of these fields.

Materials in engineering comprise all non-living matter, natural and synthetic: wood and the chemical polymers; natural rocks and concrete; metals and alloys. No engineer escapes choice among them. No engineer can learn all about them. But every engineer must learn to use effectively what is known about those that he may need at a given time.

Making sure that stationary structures remain so is a concern of every engineer. For they are not only bridges and dams, but boiler tubes and bin walls and tank bottoms, shaking-table foundations and mine pillars and smoke stacks, roads and roofs and even toilet seats.

There is nothing that an engineer does that does not involve energy transformation. Knowledge of it has a firm scientific foundation in the laws of thermodynamics. The reason that we can't let learning rest there is that those laws were formulated on the assumption of ideal conditions which have no exact counterparts in practical engineering. Hence, every control that the engineer imposes on nature calls for empirical approximations concerning the energy transformations. The scientific laws are the foundation of the machine, but empiricism keeps the wheels turning. The rules increasingly approach scientific definiteness.

Machines are man's contrivances to lessen his physical and mental labor, and/or increase the results of such labor. They are the principal direct tools in engineering control. They are essentially multipliers of force or velocity, whence the laws of physics give a good start on their analysis.

Processes rank with machines as tools of engineering control. At first blush they would seem to constitute a multitude unassimilable by any one person. This is not the fact. In the first place, every technical process is a complex that is reducible into simpler elements. If this reduction is carried far enough, each element comprises either a physical action or a chemical reaction. Thereupon the appropriate scientific laws become available to facilitate understanding and control.

The methods of analysis necessary and used in segregating the elements of machine and processes and relating them to scientific principles are the essence of engineering investigation. Teaching such methods should, it seems to me, be the primary purpose in all instruction on these two subjects.

Approximation is my name to describe the group of subjects of which "statistical analysis" and "quality control" are parts. It is the beginning of the reduction of engineering experience to mathematical routine. It is the application of the laws of probability to the repetitive operations of industrial practice. It seeks to put these operations in the actuarial class. Its endeavor is to reduce the guesswork in engineering judgment. If it succeeds — and the indications are that it will — it means that more time will be left for the engineer to wrestle with that most important element under his operating control: MAN.

Human Relations a Factor

Man, highly animate, is the medium through which the engineer must exercise his control of inanimate nature. And whereas, in dealing with nature, the counters are fact and the laws, once learned, are invariable, in dealing with men the cards are emotions with ever-changing pips.

Studies of man as a sentient being can be classified broadly into studies of groups and of individuals; of past and current happenings; the analytic and the synthetic; the critical and

Continued on Page 3, Section 2

Paper presented at the Annual Meeting of the AIME in New York, N. Y., Feb. 18-21, 1952.

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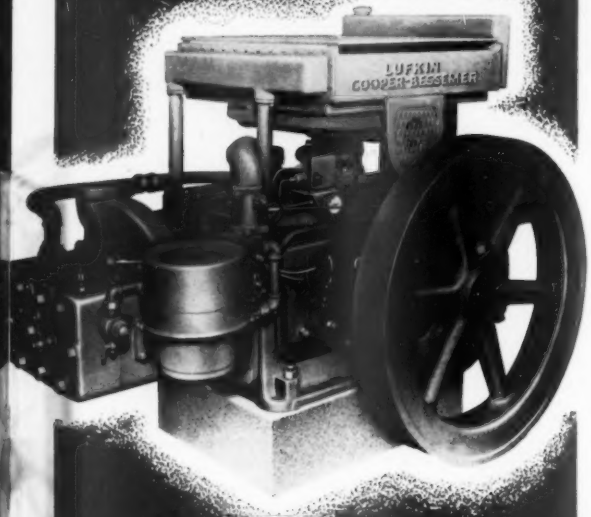

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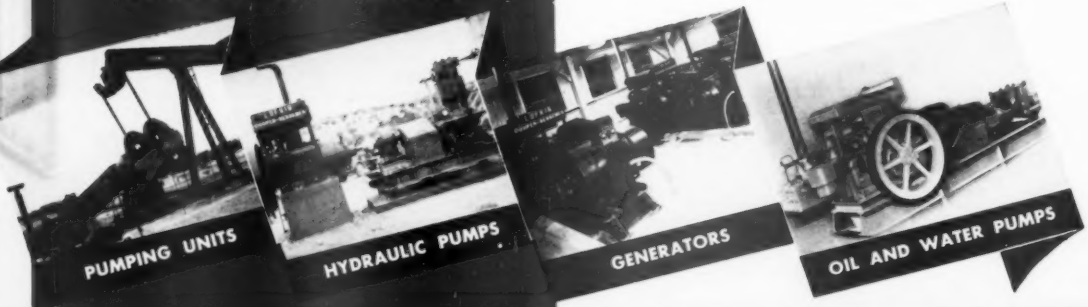

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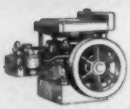
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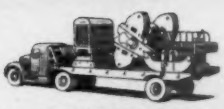
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Opportunities in Engineering and Science

By Carey H. Brown
Chairman, Engineering Manpower Commission
Engineers Joint Council

In the world today, the engineering profession faces challenges—and opportunities—as never before. Yet there is a shortage of 60,000 engineers with little relief in sight.

A TYPE of advertisement quite unusual to newspapers has appeared a number of times during the past year or more. A reader to the help-wanted ad for engineers and scientists. So far as the ads are concerned, they have been directed at engineers rather than scientists. Perhaps the engineer is considered more susceptible to the newspaper approach than his professional running-mate — perhaps he considered less fixed in location — or both. These ads are evidence of the existing shortage of engineers and scientists. This shortage is acute in certain industries and areas, less acute in others, and perhaps for the time being, reasonably well satisfied in other localities.

The output of the engineering colleges up to and including 1955 is practically fixed by the present enrollment. Through transfers, or as a result of increase efforts to reduce mortality, the number of engineers graduating in '52, '53, '54 and '55 may be somewhat increased, but not substantially so.

What *is* the prospect for graduates in these next four Junes? Based upon present enrollment in engineering courses and upon normal attrition, these figures can be quite definitely stated at 26,000 in 1952, some 20,000 in 1953, and only 17,000 in 1954. These figures are in contrast to a class of 52,000 in 1950, all of whom were absorbed immediately. In 1955 the figure will be slightly higher than in 1954 but probably well under 20,000, unless there is an unprecedentedly high transfer rate. Actually the expectancy of such transfers is limited. Usually the engineering curricula include mathematics and physics in the freshman year to such an extent that transfers from other courses would have difficulty in catching up on these subjects except at the cost of delay in graduation.

The fundamental cause of the diminishing supply of engineering graduates is the low birth rate of the early '30's. At the present time this affects not only engineering enrollment but college enrollment in general. We are now in the very trough of the curve of 17-18 year-olds. Possibly we may have passed the trough so far as engineering freshmen are concerned, since enrollment in 1951 slightly exceeded that of the previous year.

In reality the postwar classes, supplying a peak of 52,000 engineer graduates in 1950, only served to offset the meager supply of the war years, when engineering training for able bodied males practically ceased. Engineer graduates had reached a low of 8,000 in 1945. The policy of staying technical education during the war in order to provide men for the Armed Services was, to say the least, of doubtful desirability. The long term results proved very serious. The present shortage would be even worse except for the fact that the interruption was relatively short and that G.I.'s flocked to the engineering schools after the war was over.

Shortage of Engineers

The result of all these factors is a present shortage of engineers estimated at 60,000 up. Present *annual* demand has been placed at 30,000 exclusive of the needs of the Armed Services. Graduations for some time to come will fall short of meeting the *annual demand*, to say nothing of cutting into the backlog.

Superimposed on this pent-up demand, we have the rapidly accelerating technological development which brings new demands — and new opportunities — to the engineer and scientist almost every day. That this is not a mere flash in the pan is indicated by long term statistics as to the growth in numbers and importance of the engineering profession. This applies equally to the scientist. The work of one, in industry at any rate, is generally closely related to that of the other. My statistics refer to engineers however, since the Engineering Manpower Commission has devoted more specific attention to them than to the general field of science. The ratio of engineers in industry to total industrial employees in 1890 was 1 to 300; in 1906, 1 to 200; in 1930, 1 to 100; and now, 1 to 50. Where will it stop?

The problems with regard to the present shortage of engineers fall in general into two categories. The first relates to the utilization of engineers now available and the second relates to steps to be taken to increase the future supply.

The problem as to utilization of the present supply is very much complicated by the military situation. There is no means of assuring the use of engineers as such when they are called into the Armed Service, whether through the draft, from the Reserve, or by other means. This results in undue depletion of the civilian supply. The Engineering Manpower Commission has endeavored to establish the principle that engineers in unifrom must be directed into assignments which will fully utilize their engineering abilities. In addition to such efforts directed toward establishing the principle, we have also presented for consideration a great number of individual cases of misapplication of engineering training and ability. Considerable progress has been made in this respect but the situation is not as it should be.

We cannot hope to match our potential enemies in numbers of men. We must out-design and out-produce them in order to emerge victorious. It is in our engineering, scientific and productive skills that our superiority lies.

Law of Supply and Demand

Efforts to secure better utilization of engineers in the Armed Services are often met with the accusation that private industry is doing a poor job in this respect. No doubt that is true in many cases. I believe that we can look for best results, not as a consequence of any action which we may take now, but as a result of the workings of the law of supply and demand. The nature of the activities of engineers engaged in sales, purchasing, and the like varies so much from place to place that it is impracticable to make any sound generalization with regard to justification for the use of engineers in

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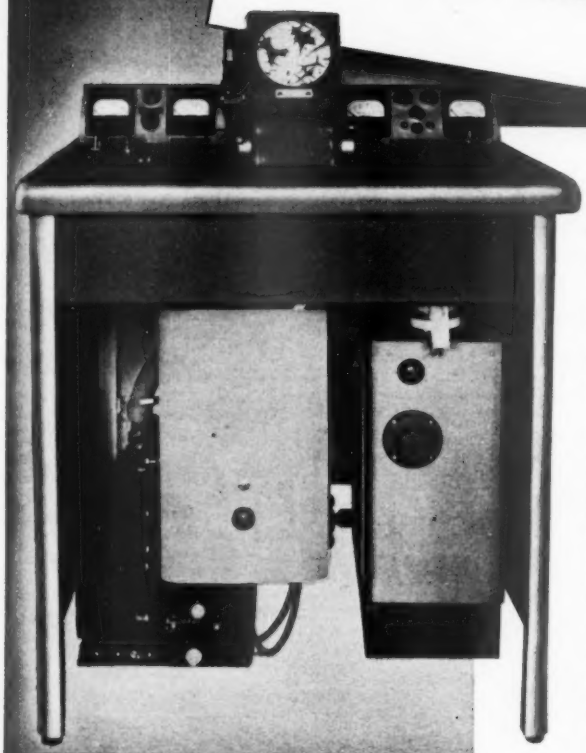

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Characterizing Features of the Petroleum Engineer

By Harry H. Power, Member AIME
Professor of Petroleum Engineering
University of Texas

A petroleum engineer is characterized by his ability to apply scientific principles to plan for the development of an oil or gas field. Therefore, says the author, he is expected to show professional attitude and competence in all work phases.

AN examination of curricula for accrediting purposes requires that the term *engineering* as applied to the special field be defined in order that it may be characterized and differentiated properly from other engineering fields. Little difficulty has been experienced in the characterization of curricula of long standing, such as civil, mechanical and electrical engineering. Some believe that a field such as petroleum engineering, is characterized as a specialization in the function of engineering, while other fields such as geological engineering and engineering physics are associated with the basic sciences. Often, the principal problem confronting an examiner of a college engineering program is: "Should this curriculum be considered as engineering leading to an engineering degree?"

Not only is the characterization of a curriculum important for accrediting puropses, but it has assumed considerable importance of late in the licensing of professional petroleum engineers.

All engineering curricula have certain features in common, which include:

1. Basic science
2. Applied science
3. Applied engineering subjects

Engineering curricula are often characterized solely by courses in mechanics, strength of materials and properties of materials. Based on these studies are to be found such courses as "structures, apparatus or machines and the principles upon which they are designed, constructed and operated." We recognize the verb *to engineer* by the definition: " to plan and direct the formation or the carrying out of; to guide or manage by ingenuity and tact; to conduct through or over obstacles by contrivance and effort"[1] The one quality which the engineer has which the others do not have is the process of linking the findings of science to the accomplishment of useful devices for the advantage of the people. In this endeavor he designs *creatively* with a scientific basis and as an end result he promotes an efficient and economical process, the saving of life and property and a higher standard of living for the public. The root of this all has been attributed to the matter of design.[2]

Design or Planning

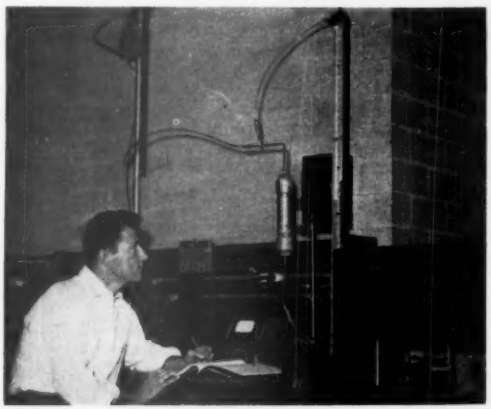
By *design* was meant originally "the process of contriving a scheme, system or concept of a device, together with a forecast of behavior thereof, which if built would be appropriate to the functional, economic and safety requirements."

Accordingly, Dean S. C. Hollister of Cornell and President of the American Society for Engineering Education, has proposed the following statement in answer to the question of characterization of engineering curricula which was raised by the Engineers' Council for Professional Development:

"An engineer is characterized by his ability to apply scientific principles to design or develop structures, machines, apparatus or manufacturing processes, or works, utilizing them singly or in combination; or to construct or operate the same with full cognizance of their design and of the limitations of behavior imposed by such design; or to forecast their behavior under specific operating conditions; all as respects a specific function, economics of operation and safety to life or property."

Other engineering educators are in sharp disagreement with this concept insofar as it is intended to characterize *all* engineering curricula. Robert E. Doherty, president of the Carnegie Institute of Technology, states:[3]

"Our primary reservations are in regard to the proposed adoption of 'ability to design' as the distinguishing quality — the 'significant and distinctive element' — that differentiates the function of an engineer from that of his professional cousin in adjoining fields; and therefore in regard to the adoption of 'the process of analysis and synthesis essential to designing' as the sought-for 'differentiating characteristics contained in an engineering curriculum' . . . ability to design . . . characterizes some, but certainly not all, of such functions . . . Dr. R. F. Mehl tells me that to accept the Committee's premise that ability to design is the distinguishing characteristic . . . of the function of an engineer is to throw out practically all of metallurgical engineering and most of the branches of engineering embraced by the AIME."



ELECTRIC RESISTANCE studies are conducted on cores by students at the University of Texas Petroleum Engineering laboratories. Here Student Lee S. Carter makes a measurement.

Paper presented at the AIME Annual Meeting in New York, N. Y., Feb. 18-21, 1952.

James B. Macelwane, dean of the Institute of Technology, St. Louis University, comments on the general characteristics common to all engineers.[2]

"There would seem to be three characteristics of the professional engineer on which all can agree. In the first place, an engineer must be equipped with a sufficient store of fundamental scientific knowledge as will enable him to solve the problems that are inexorably thrust upon him in the practice of his profession. In the second place he must have acquired the technical skills that are required for planning and design of structures, apparatus, circuits, processes, or procedures in his field that will give the optimum performance at the least cost, and he must be capable of making a reliable estimate both of the performance and of the cost so as to obtain the most for the outlay that is justified by the foreseeable overall returns. Thirdly, he must be a capable manager and must know how to deal with men."

It must be admitted that *design* as defined originally by Hollister is an important factor to the production engineer in the oil industry. Mechanical equipment must be designed to meet the usual requirements of drilling and production. Although this function is assigned, ordinarily, to the mechanical engineer, the production engineer should know something about design and manufacturing processes if he is to select equipment intelligently for the efficient and economical drilling and operation of oil wells. It is agreed that his work on the drafting board, as compared with that of the mechanical engineer, will usually be a minimum, but, at the same time he should be *design conscious* if he is to work understandingly with the engineers of the supply houses and manufacturers. Parenthetically, the engineers designing oil field equipment should be *operation conscious* if they are to work understandingly with the field, for it is only with a full understanding of each group of the other's problems that the best results can be obtained.

With respect to the petroleum reservoir, Millikan[4] reports that some difficulty is apparent in convincing the average engineer that (remote) control of engineering processes one or two miles underground without physical contact is really engineering.

However, if the characterizing features of engineering are to include not only the ability to design, but also to *construct, operate,* and *forecast,* a more rigid differentiation with respect to petroleum engineering may be proposed. The laying out of an oil field, the spacing of wells, the determination of hole size, the determination of casing programs and the selection, placement and operation of producing equipment, and the production of oil and gas from petroleum reservoirs to meet definite objectives require many of the elements of design, but admittedly of a different order in many important directions from the concept of design as defined by Hollister and practiced by the mechanical engineer. The functions just mentioned are as inherently characteristic of petroleum engineering as the layout and sinking of a mine shaft, timbering, hoisting, other preparations for the extraction of ore and the actual mining operation are to the mining engineer.

The principles involved in modern reservoir engineering are considered to be basic to the generalized concept of design as applied to the development and exploitation of oil fields as outlined above.

Muskat[4] believes that "the petroleum engineer should do more than merely plan operations; he should be able to interpret and understand what is happening in the operations. His job should not terminate when he has completed his design, as would perhaps the designer of a bridge, or an architect. He must continue to study and interpret what is happening to the installations and operations which he has designed."

Trostel[1] is of the opinion that "an engineer should obtain and select fundamental data relating to design or operations and by analyzing such data through application of scientific and *economic* principles, develop and recommend a preferred design, method of operations, or procedure. This statement relates the fact that nearly all engineering problems require the application of both science and economics simultaneously . . . the position that economics plays in the role of engineering should be stressed in all categories; *i.e.,* an engineer, in most cases, should design or predict in accordance with best economic results. Finally, an engineer normally *recommends* a preferred design or method of operations, or possibly contrasts the favorable features of more than one, so that management can make the final decision or selection as a matter of business policy."

Likewise, Macelwane[2] states: "In his planning, the engineer must solve two problems. In the first place, he must decide what is the most effective procedure that can be applied in the given circumstances. Secondly, he must weigh the performance of the various methods against the economic limitations of the case so as to secure the maximum of useful information at the least justifiable cost."

Accordingly, after the foregoing reasoning, both the planning and execution of projects will require a thorough training in the basic and applied sciences underlying petroleum engineering. Unless the petroleum engineer has this background, "he cannot choose intelligently either the sciences to be applied or the method of their application. Without this background he will neither know the limitations of the method itself nor will he realize the pitfalls of instrumentation and interpretation. He must not be merely a scientist, however competent. He must be able to superpose on his thorough knowledge of basic and applied science the practical economic outlook of the engineer if he is to forecast intelligently either performance or the cost."

Hence, if the concept of "design" (or planning) is to include the prediction of operating results and profits, the characteristic features of petroleum engineering become increasingly apparent.

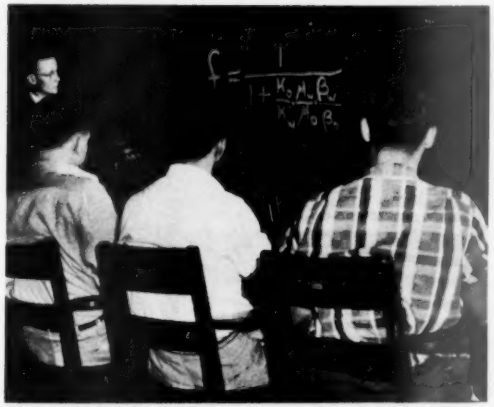
Economics

In common with all engineering branches, economics, obviously, is an essential element and basic to all problems of design, prediction and other characterizing features of the profession.

The preparation of a budget, an authority for expenditure, or a bill-of-materials involves the application of engineering cost accounting and cost estimating, with differentiation between the items classified as *expense* and those which are *capitalized,* and the proper retirement of the latter through allowances for depreciation, depletion, obsolescence and amortization. In common with most engineering problems, the questions: "will the project pay?"; "why do it at all?"; and "why do it now?"; are involved in economic selection.[7] The choice may lie between two or more projects or merely between a given project and no enterprise at all.

With respect to the payout, the petroleum engineer is interested primarily in whether the enterprise will pay in the *long run.* Hence, such an investigation demands a thorough analysis of investment, operating costs, fixed charges, depreciation and maintenance costs.

The petroleum engineer should also be tax conscious and know the role which taxes can play in the profitability of different types of operations. Unless the latter should lead to profits he will soon be out of a job.[4]



THEORY COMES FIRST in engineering education. Here, in a classroom at Louisiana State University, students work out a basic formula.

Job Classifications

Hubbard[4] comments that "the engineers operating in the oil fields today are largely specialists, whether they be electrical, mechanical, civil, construction, chemical, or petroleum engineers. Although most of the younger men in the field are engaged in more than one of these specialities, they are usually under the direction of a specialist who specifies or directly supervises the operations in a general way. The next higher echelon is usually the chief petroleum engineer, assistant superintendent, superintendent, or higher supervisor who has achieved a working knowledge of most of the branches of engineering applied in the oil and gas fields by many years of experience." Although this latter man perhaps has progressed beyond the status of 'petroleum engineer' to that of manager, it is not contended that he alone best qualifies for the characterizing features of the petroleum engineer. It is believed that the role of the young engineer, even though limited to a very small operation, is one that can be characterized in some degree by all the elements that define the mature and experienced professional engineer. We may designate the engineer 'junior,' assistant,' 'associate,' or 'senior,' which may indicate the degree of professional competence with accumulated experience, but still he should qualify professionally by every test that characterizes a petroleum engineer.

In view of the foregoing, a petroleum engineer will be expected to show: (1) professional attitude, and (2) professional competence. The professional attitude of an engineer is similar to that of the public servant who acknowledges his social responsibility to his client and to the general public welfare.[5] Professional competence requires that the petroleum engineer have the knowledge and skill necessary to use basic and applied science for the practical (economic) solution of any problem with which he is confronted.

In one instance, it was thought to be simpler to define "petroleum engineer" without reference to "design" (planning), but in more commonly accepted terms such as: "the petroleum engineer is characterized by the application of the basic and applied sciences to practical problems in connection with the drilling for and the production of petroleum."[6]

The question is raised: how would this definition be of use to a State Board of Registration for Professional Engineers confronted with the differentiation of petroleum engineering from some other branch of engineering or applied science engaged in drilling and production operations?

Ordinarily, the junior engineer with a degree in petroleum engineering will acquire the necessary job experience in the oil producing industry to qualify as a professional petroleum engineer. If the junior engineer has a degree in some other branch of engineering, such as chemical or mechanical engineering, the registration boards for professional engineers will be confronted with the problem of whether experience in the field together with a program of self-study will eventually qualify the candidate as a professional petroleum engineer. Other professional people who do not hold engineering degrees, but who acquire practical experience in the oil fields may have a much more difficult time in gaining recognition as professional petroleum engineers.

In conclusion, the petroleum engineer is characterized by his ability to apply scientific principles to plan for the development of an oil and/or gas field, utilizing those elements of design in the broad sense and the principles of reservoir performance which are unique in the problems of spacing, well drilling and exploitation. He is also characterized by his ability to operate the oil and/or gas wells comprising a pool with full cognizance of their design and of the limitations of well and reservoir behavior imposed by such design; and by his ability to predict the operating results from certain production practices which stem from various basic and applied sciences, which include the principles of reservoir performance and aided by certain techniques perfected in the field. The foregoing characterizing features are in respect to a specific function, economics of operation with due consideration to human relationships and safety to life or property.

ACKNOWLEDGMENT

The author acknowledges gratefully the helpful suggestions of the following engineers and administrators from industry in the final preparation of this paper: C. V. Millikan, John Domercq, Jr., A. G. Copeland, I. W. Alcorn, S. C. Oliphant, T. A. Huber, S. F. Bowlby, Paul D. Torrey, Paul Hubbard, N. van Wingen, M. I. Taylor, J. B. Umpleby, Morris Muskat, Paul Andrews, M. L. Terry, E. G. Trostel, M. L. Haider, J. I. Laudermilk, Jack Berlin, A. C. Rubel, R. W. French, and others.

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Evaluating A Petroleum Engineering Curriculum

By Holbrook G. Botset, Member AIME

Head, Petroleum Engineering Department
University of Pittsburgh

Well-rounded, capable engineering graduates may be attained only by properly integrating various components of education such as an adequate curriculum, quality of faculty, academic atmosphere, student contact and guidance.

ENGINEERING manpower is becoming scarcer every year. According to the best estimates this shortage will continue for some years into the future. It is, therefore, of great importance that the graduates of our engineering colleges be of as high caliber as possible. Our colleges should turn out real engineers, not glorified mechanics or technicians. It, therefore, seems important to give some consideration to the basic elements which should be the principal components of an adequate undergraduate petroleum engineering curriculum.

As will be seen later, there is no desire or intent to imply here that all petroleum engineering curricula should be set to a fixed pattern. Considerable latitude in such curricula is most desirable so that the industry will obtain men with varied backgrounds to fit into the various types of petroleum engineering jobs which always exist, provided the curricula contain those courses which are basic to all branches of the engineering profession.

In considering the criteria of an adequate curriculum for petroleum engineers, two definitions should first be established: That of an engineer and of a petroleum engineer. One can find in the literature many definitions of an engineer. Earlier definitions almost always had to do with design, *i.e.* an engineer is one who designs structures and processes. More modern concepts lead to the picture of an engineer as one concerned with "the application of science in an economic manner for the benefit of mankind."[1]

According to this definition, which will be adopted in the following discussion, an engineer does not necessarily design structures or processes, but is anyone who makes practical application of basic science. Thus, for example, we have reservoir engineers, production engineers, natural gas engineers, none of whom has necessarily anything to do with design *per se*, but all of whom apply basic science to the solution of practical problems.

The second definition to be established is that of a petroleum engineer. A petroleum production engineer may be defined as one who applies fundamental science to the solution of problems involved in the drilling and development of oil and gas fields and the transportation of oil and natural gas. The area of possible activities of a petroleum production engineer is thus a very broad one. Graduates in petroleum engineering may be employed in any one of a dozen different specializations. It is obviously impossible to cover all of these specializations adequately in any undergraduate curriculum. However, it is certainly true that a petroleum engineer well trained in the fundamentals should be able adequately to cope with the technical problems involved in any one of the various possible specializations.

Paper presented at Annual Meeting of AIME in New York City, Feb. 18-21, 1952.

Three Fields of Knowledge

On the basis of the above definitions, an engineer's education should emphasize three fields of knowledge: Basic science, economics, and humanities, since he has to make practical applications of basic science, and also to deal with people and organizations in a complex industrial economy. It would seem apparent that any acceptable engineering curriculum should contain the fundamentals of the above three fields, with enough work in his specialized field to give the student a picture of the *type* of application which he will likely be called upon to make in practice. This is recognized by the Engineers' Council for Professional Development in its emphasis on the necessity for any engineering curriculum to contain the fundamental engineering subjects: Mathematics, physics, chemistry, theoretical and applied mechanics, thermodynamics, fluid mechanics and basic electrical engineering; with about 20 per cent of the curriculum devoted to nontechnical subjects such as economics and humanities.

With a thorough grounding in these fundamentals, an engineer should be able, as stated above, to handle any practical problems that may arise, but if he does not know the fundamentals thoroughly, he certainly will not be able to make many successful applications to these practical problems.

A real engineer is one who knows the basic principles on which equipment and processes operate, and who can create new methods and techniques. Engineering education, then, should be much more than the training in how to operate equipment, although some institutions appear to place much emphasis on such courses.

There is a distinct different between engineers and technicians. Members of the latter group are able to operate with facility all kinds of technical equipment and machinery, but

are usually incapable of designing new processes or methods, or of analyzing a technical problem to find the basic elements which will ultimately permit its solution. In the limited time available in a college curriculum, if emphasis is placed on the mechanics of equipment operation, then inadequate knowledge of the fundamentals will be obtained.

It seems apparent that any properly designed engineering curriculum should contain and emphasize fundamental engineering subjects.

Specialized Knowledge

What specialized knowledge does a petroleum engineer need? The first area that comes to mind is that of geology; certainly anyone working in production problems needs a knowledge of the fundamentals of geology. Beyond this there are two fields the fundamentals of which a petroleum engineer should know — natural gas engineering and reservoir engineering. No matter in what area of activity a petroleum engineer may be employed upon graduation, a basic knowledge of reservoir engineering would certainly appear to be important since most production problems are directly related to the extraction of oil from the reservoir.

An undergraduate reservoir engineering course should contain, not methods of making material balance calculations, but the basic physical concepts involved in reservoir fluid mechanics. P. H. Bohart, speaking of the engineering graduate, states "It is not necessary for him to know how to make a material-balance computation but very necessary that he be thoroughly grounded in mathematics and physics."[2] It is also apparent that an adequate knowledge of the behavior and properties of natural gas is vital to anyone working in petroleum production.

Various petroleum engineering schools will naturally emphasize different aspects of the specialization depending upon the primary field of interest of the staff. Some will emphasize mud problems; some, reservoir engineering; some, secondary recovery; etc. This is suitable and desirable, for if companies indulge (as many of them do) in the practice of acquiring graduates from various schools, the result is a staff of broad and varied background. However, the specialization should be a minimum, consistent with giving the student a speaking knowledge of the petroleum engineering field. Too much emphasis on specialization in the undergraduate curriculum is bound to lead to a slighting of the fundamentals.

The vast majority of undergraduate students, because of lack of experience, cannot grasp the import or significance of the various sub-specializations, such as well logging, mud engineering, corrosion, water flooding, etc., as far as their own future activities in these fields are concerned. It is a waste of time, therefore, to emphasize these too much in the curriculum. The period of specialization should be at the graduate level after the student has had a chance to acquire some practical field experience and also to appraise the various fields of specialization and decide on the one (if any) in which he is particularly interested. It would appear that then is the time for specialized training which should be obtained by graduate work at the institution which is most interested and competent in the particular specialized field.

Since an engineer must be practical and must deal with people, it is vital that the fundamentals of economics be contained in the curriculum and that an adequate background in the humanities be included to produce a well-rounded man. Our present civilization is largely a technological one, and many major decisions and policies in industrial operations must be based to an appreciable extent on technical factors closely inter-related with political and economic forces. Therefore, it is noticeable that in major industries generally, more and more executives are being chosen from the ranks of engineering.

Because of the close integration of technical, political and economic factors in modern complex industry, it would appear that an engineer who has had some fundamental training in these areas will be a better executive than one who has not. As a result of this need for engineers in executive positions and the inadequate background which most engineers seem to have in economics and industrial relations, many corporations are, at considerable expense, sending select groups of engineers whom they plan to make executives to certain universities to take specialized curricula in management problems. If these highly competent engineers were better grounded in economics and industrial problems, these expensive training programs would be minimized or eliminated.

Ability of Expression

One of the major factors influencing the rate of advancement of a man in any field of endeavor is his ability to express himself clearly and succinctly. In many cases, even among engineers, the rate of advancement is more dependent upon this ability than upon technical knowledge. In spite of this rather well recognized fact, one of the great and obvious defects of the average engineer is his lack of ability to express himself orally and in writing. The importance of English in the engineering curriculum cannot be over emphasized. English is the basic tool of engineering just as is mathematics or physics, and poor English should be just as subject to criticism in an engineering paper as poor mathematics. Many of the technical papers published today are poorly written. Sentences are so badly phrased that they are ambiguous. If a man thinks clearly, he should be able to write clearly. It is unfortunate that many members of engineering faculties use rather poor English and seem to be indifferent to grammatical errors made by students. If the engineering faculty does not set the students a good example in the matter of self-expression, the task of the English Department becomes pretty hopeless.

The personal element in education is one aspect of undergraduate engineering education which is rarely discussed and which is of considerable importance.

The emphasis which some institutions seem to place on size and numbers is probably not good education. In many cases where enrollments are high, undergraduate classes are largely taught by graduate assistants. If a university is really interested in doing a good job in education, the regular permanent faculty will do the undergraduate teaching, because that is the level at which good teaching is very important and only rarely will it be obtained from graduate assistants. In spite of all the plans and programs set up, the school which has the more personal contacts between faculty and students will be likely, if it has a competent faculty, to turn out better men.

An adequate engineering educational program involves many factors, and it is only by properly integrating the various components such as curriculum, quality of faculty, academic atmosphere, student contact and guidance, etc., that the objective: well rounded, capable engineering graduates may be attained.

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Staff Problems Relating To Engineering Education

By Charles F. Weinaug, Member AIME
Chairman, Petroleum Engineering Dept.
University of Kansas

Industry benefits, or suffers, most from the well-being of our educational system. Therefore, according to the author, industry should take the direct initiative in seeing that high standards are maintained in our colleges and universities.

DURING the past decade education has passed through a period of adjustment including disproportionately increased enrollments and insufficient staffs. The condition was brought about as a result of the G.I. bill of rights; however, even after the bulk of veterans have graduated a series of reactions have continued to occur which have created unprecedented problems for the educator.

To meet the need of larger staffs some personnel was obtained from industry; however, the principal source was from part time graduate students who were veterans taking graduate and refresher work. In some cases even undergraduate students filled in temporarily, or else classes were combined to help take care of the unusual teaching load.

These methods, while not entirely satisfactory, did solve the problems of this period for several reasons. A large number of the students were returning veterans who were considerably more mature than the average student. These veterans were old enough to have remembered the effects of depression. Many of them had assumed family responsibilities, and almost every one had a definite career or profession he wished to follow. It was not necessary to inspire these students, and in most cases even experienced instructors found it difficult to keep ahead of them. Such enthusiasm affected even the younger students, and standards of attainment were maintained, or raised, in spite of inadequate and inexperienced staffs.

Paper presented at the Annual Meeting of the AIME in New York, N. Y., Feb. 18-21, 1952.

THE AUTHOR (center) teaching his students at the University of Kansas principles of pipeline flow.

Industry Demand for Graduates

Since the veteran and total enrollment has decreased it would seem that the problem of inadequate staff should have automatically solved itself. However, this has not proved to be the case. Other factors have affected the situation. Contrary to expectation, the number of graduates has decreased and the demand by industry for engineers has increased. The resulting shortage of technical personnel has brought not only higher starting salaries, but glowing promises for future advancement. Almost all students who, under normal conditions, would have taken graduate work, have been prematurely attracted into industry. Not only has this eliminated the possibility of graduate students becoming part time instructors, but it has also made teaching at the undergraduate level much more difficult. The student has a growing tendency to assume the attitude that all he needs is a degree to become a "vice president." Such has been the competitive demand by industry for graduates, regardless of ability or scholastic attainment that quality of work is no longer a primary object to the student.

Also, during this period the average age and maturity of the college student has decreased. The student today has assumed very few of life's responsibilities and has no definite objective in mind. He is not sure where he is going or why. He is, in short, a product of our times. He needs the best guidance, leadership and inspiration that can be supplied, if he is to be adequately prepared for the responsibilties he will face.

It is impossible for the instructor of large classes to meet such a challenge, since the individual student cannot be considered in the crowded classroom under such conditions. To teach effectively, the instructor must be able to divide large sections, and offer courses at more frequent intervals. Even in the larger departments where small classes have been maintained the decline in enrollment has not been sufficient to offset the decrease in available graduate assistants, part time instructors, and permanent staff.

The increasingly attractive offers of industry have, of course, taken their toll from the ranks of the experienced instructors as well as from those who might otherwise enter the teaching field. This factor alone has had a most debilitating affect upon the vitality of the profession, since many of the best instructors have left the field. Only a decrease in the quality of young engineers entering industry can possibly result from such a situation.

Along with this will eventually come a progressive decline in the technical advances industry has been making, since the young engineer who has not been inspired by competent leadership and guidance seldom rises above the goals set

during the formative years of his chosen profession. Therefore, it is imperative that something be done to prevent any further loss of instructors to industry, and to attract competent new men into the profession as well. To accomplish this goal salaries will have to keep pace with those in industry, and present so-called teaching duties will have to be reduced.

Non-Engineering Courses

The teaching load should be decreased in order to give the instructor time to study and incorporate the large quantity of new material being published. He should have time also to reflect on events affecting human affairs so as to be able to stimulate in the student not only an interest in technical advances alone, but also to prepare him for his place as a responsible, well-rounded citizen. The engineering graduate has been severely criticized for his lack of participation in community affairs. He will not likely become interested in these matters by taking a few superficial required courses in the humanities; and because of his course load there is time for no more than that in the engineer's curricula. He must be shown the imprint current events, political and cultural, are making on his chosen profession by a well oriented instructor who has a thorough grasp of such subject matter and who is capable of imparting its essence to his students. Thus, the technical student can be stimulated further to take his proper place in the broader affairs of the community. This latter point has not been emphasized in recent discussions regarding more courses in the humanities. However, the result hoped for by this demand cannot be attained by placing the entire burden on people in another field. The engineering instructor must also assume his rightful share of this burden by a more thorough integration of subject matter than has recently been possible.

The instructor should be able to devote some time to research also, as it is the most effective means of keeping alive a vital growing interest in his field of study. One cannot perform research and stagnate at the same time. While our country is making tremendous strides in the application of existing fundamental concepts, it has been criticized for making few original contributions to this fund of knowledge. It is time the instructor be released from financial pressure so that he may be able to perform research for the advancement of fundamental knowledge alone, rather than being forced from economic necessity to take in routine consulting jobs.

It is right that we expect the university to take the initiative in promoting the advancement of learning, since it has always been one of the best places to carry on such experimentation. However, it cannot continue to meet the growing challenge unaided.

The present trend toward lower standards can be reversed only by additional aid for schools. This financial support can be supplied in several ways. The states can increase their appropriations to the state supported schools. However, this would necessitate vigorous support from every quarter possible.

Some are looking to the federal government for help through the National Science Foundation, research contracts from government agencies, and outright grants. These can result only in another form of increased taxation. However, there are other possible dangers. These well intended plans can readily become the first step to federal control, by the well known method of supplying enough assistance that the institution becomes dependent upon this aid; then policies are dictated and education becomes government controlled. Also, present government research contracts have a tendency to be directed toward specific goals in order to be justified. Only applied research projects are usually considered. The result is to further preclude the possibility of contributing to basic fundamental knowledge as such.

Financial Aid from Industry

The only other appreciable source of possible aid can come from industry and its sponsored foundations. If universities are to progress or even maintain their present standards without federal support, a way must be found for industry to provide additional financial assistance. The present fellowship and scholarship programs, while a step in the right direction, are inadequate, either to attract sufficient graduate students to supply the industrial demand for men with advanced degrees, or to augment the available ranks of capable instructors.

Some possible supplementary plans are suggested here which may offer a solution. Industry might retain instructors to do fundamental research in their various fields to supplement present research staffs. Since the instructor would not be as readily available as the research man to assist industry in its day to day production problems, the company would be assured of some continuous effort being directed toward a better basic understanding of its problems. At the same time it would relieve the instructor of the financial necessity of accepting every routine task presented, and it would free him to concentrate on more vital problems. Under these conditions university staffs can be expected to advance the frontiers of science by contributing to basic information, and to produce better trained men as well.

Also, direct contributions to endowment associations of the university might be made by establishing "chairs" in the various science and engineering departments. Either the principal, or the income, from these funds could be used to pay, or supplement, the salary of the instructor so that it would be comparable to the salary he could be receiving in industry.

These methods may be varied and adapted and others created, so that this responsibility may be equally distributed among those interests which reap the greatest profit from the well-being of our educational system. Since industry benefits most from a superior quality of engineering education afforded by the university, or suffers most when this quality is lowered, it is reasonable to expect industry to take the direct initiative in seeing that the highest possible educational standards continue to be maintained.

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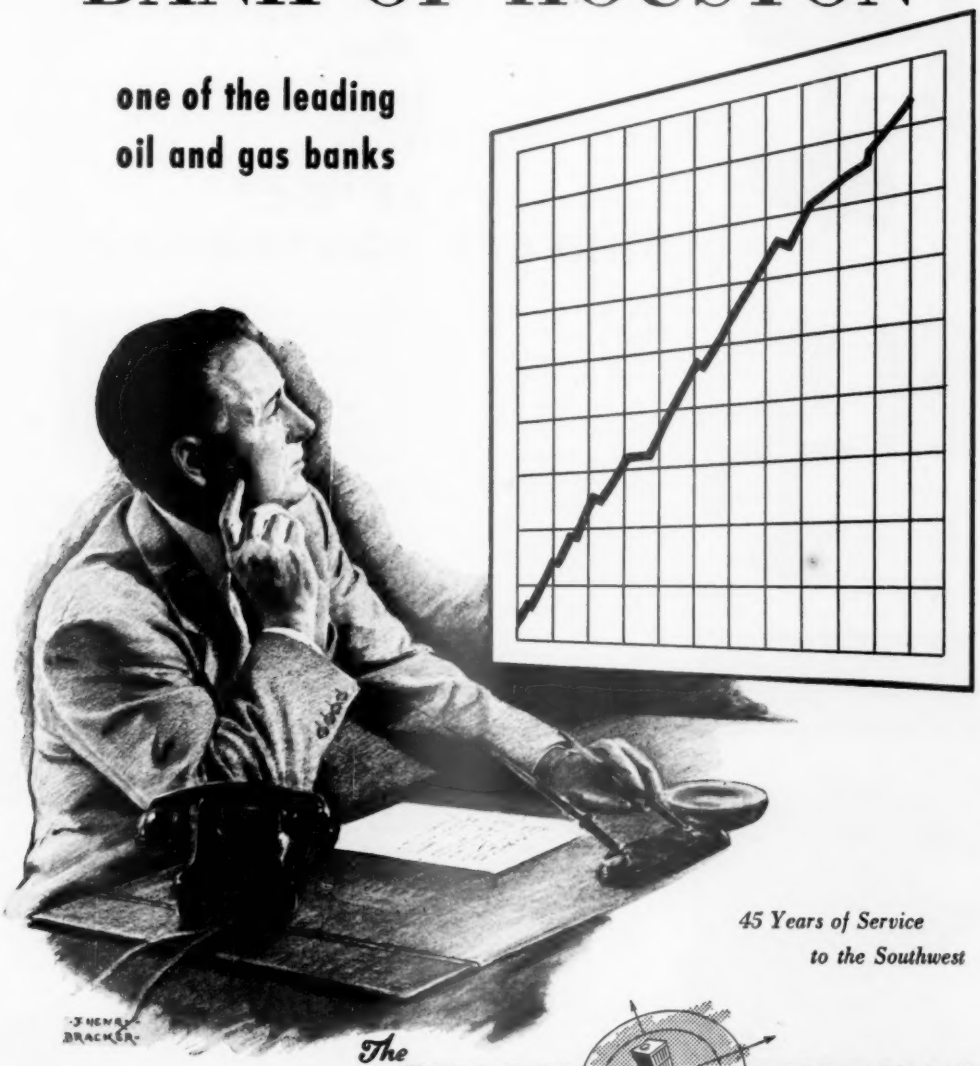

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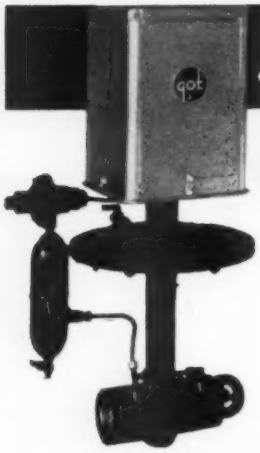

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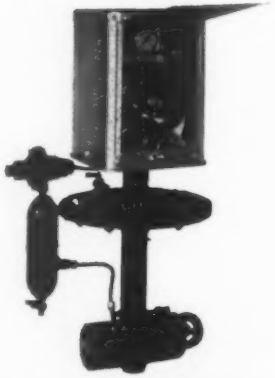

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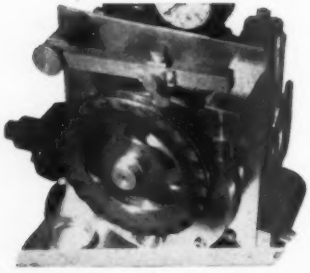

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*BEHAVIOR OF DISSOLVED OXYGEN IN OIL FIELD BRINE**

GEORGE G. BERNARD AND GLENN A. MARSH, THE PURE OIL CO., CRYSTAL LAKE, ILL.

ABSTRACT

It is often assumed that aerated oil field brines which are to be injected underground contain dissolved oxygen in amounts which will cause appreciable corrosion. Through the use of a new portable dissolved oxygen meter, accurate determinations were made at three brine conditioning plants. At two older plants, dissolved oxygen concentration in the final treated brine was found to be almost zero in spite of aeration during the conditioning process. At a new plant, dissolved oxygen was initially present but disappeared soon after the brine was "inoculated" with oxygen-free brine from one of the other plants. Corrosion tests at the two older plants have substantiated predictions that the brines would not be corrosive. These results show that mechanical deaeration may not always be required in brine treating plants.

INTRODUCTION

The present work was undertaken to add to our knowledge of aeration and deaeration of oil field brines in brine conditioning plants. It is commonly assumed that brines which are exposed to the air soon become more or less saturated with dissolved oxygen. Since oxygen-containing brines are known to be corrosive, precautions are often taken to keep air out of brine through the use of closed systems or mechanical deaeration.

The study of oxygen in brine has been seriously hampered in the past because of the lack of a suitable analytical tool. The standard Winkler method for the determination of dissolved oxygen is satisfactory for use in fresh water, but not in many oil field brines. Corrections have to be made for a number of reducing substances such as ferrous iron and hydrogen sulfide which are commonly present in natural brines. Very often the correction factors are much greater in magnitude than the amounts of oxygen which are to be determined, and consequently erroneous results are obtained. Also, erratic Winkler data are obtained when appreciable concentrations of calcium and magnesium salts are present.

The first step in carrying out a systematic study involved designing a portable dissolved oxygen apparatus which would operate in natural brines. Subsequently, this apparatus was used in three brine conditioning plants. Dissolved oxygen data obtained here, and certain corrosion rate data, illustrate the interesting behavior of oxygen in these oil field brines.

APPARATUS

A portable dissolved oxygen meter described in detail elsewhere,[1] was developed specifically for use with oil field brines. It is a polarographic apparatus employing a small rotating platinum electrode (cathode) and calomel reference electrode (anode). A potential of 0.7 volts is applied across the electrodes while they are immersed in the brine to be tested.

Manuscript received in the Petroleum Branch office Aug. 15, 1951.

*This paper is Part 3 of the paper entitled "Behavior of Dissolved Oxygen in Brine" which was presented at the Fall Meeting of the Petroleum Branch in Oklahoma City, Okla., Oct. 3-5, 1951. Part 1, "Portable Dissolved Oxygen Meter for Use with Oil Field Brines," was published by *Analytical Chemistry* (Ref. 4 of this paper). Part 2, "Reaction Between Ferrous Iron and Dissolved Oxygen in Brine," is in publication by *Industrial and Engineering Chemistry* (Ref. 2 of this paper).

[1]References given at end of paper.

Table I — Composition of Brine at Oklahoma Plants

Constituent	ppm Present at Plant "A" near Delaware	Plant "B" near Delaware	Plant near Madill
Hydrogen sulfide	150	150	0
Calcium	5,650	3,142	12,360
Magnesium	1,352	840	1,790
Sodium	37,688	18,238	31,600
Iron	0	0	0.5
Bicarbonate	282	260	114
Chloride	71,889	35,700	75,483
Sulfate	330	1,186	469
Dissolved Solids	116,861	68,500	125,550
pH	6.5	7.0	6.4
Sp.G. (60°)	1.080	1.042	1.098

Current through the electrodes, at a given temperature, is a linear function of dissolved oxygen concentration, and is measured on a microammeter.

The instrument, being portable and direct reading, is simple to operate and requires only 30 seconds to make a determination. The results are reproducible within 0.05 mg of dissolved oxygen per liter of brine, with an accuracy of about ±5 per cent.

The accuracy of the dissolved oxygen meter is not affected by the presence of a number of common substances, which include ferrous, ferric, sulfide, calcium and magnesium ions, and various organic compounds. This interference-free operation has permitted a study of the reaction between ferrous iron and oxygen in brine over the pH range from five to nine,[2] as well as the study of oxygen in natural brines described here.

PROCEDURE

Determining Dissolved Oxygen in Three Brine Conditioning Plants

The first step in the procedure was the determination of dissolved oxygen concentration at various points in three brine conditioning plants. These plants are located in Oklahoma, two near the town of Delaware (designated as Plants "A" and "B"), and the other near Madill. The dissolved oxygen meter was used here, because it had been found that these brines yielded uncertain results with the Winkler method. The compositions of the brines are given in Table I. The dissolved oxygen data are given in Tables II, III, and IV.

Determining Corrosion Rates of Steel in Oil Field Brines

Corrosion tests were carried out at both Delaware "A" and Madill, subsequent to the dissolved oxygen determinations. Clean pipe nipples were weighed before and after seven to eight months of service to establish the corrosion rate. The nipples were also inspected for tuberculation and pitting. Results of these tests are given in Tables V and VI.

RESULTS

Results of Dissolved Oxygen Determination in Three Brine Conditioning Plants

Tables II and IV show that at two of the plants where dissolved oxygen determinations were made, namely Delaware "A" and Madill, the oxygen concentration in the plant effluent was very low in spite of the fact that no mechanical deaeration was used. The oxygen concentration increased with forced aeration, of course, but decreased rapidly on standing, even in the presence of air.

Table III shows that at the third plant (Delaware "B"), the dissolved oxygen concentration was initially high when the plant started up. The brine in this plant was then inoculated with oxygen-free brine from Delaware "A", two weeks after startup. One week after inoculation another determination showed no oxygen in the Delaware "B" brine. This absence of oxygen has been confirmed in subsequent tests.

In all cases where little or no oxygen was found in brine, the operation of the meter could be checked by blowing air through the brine sample. After a short period of such aeration, the sample would yield a reading of one or two mg of dissolved oxygen per liter.

Results of Corrosion Tests at Delaware "A" and at Madill

Corrosion rates as determined on test nipples which have been in service for seven to eight months were reasonably low (Tables V and VI). At Delaware "A", the average rate

Table II — Analysis of Brine for Oxygen at Plant "A" Near Delaware, Okla.

Description of Sample	Mg Dissolved Oxygen per liter of Brine
Brine from supply well	0.4
Brine after third aeration	2.3
Filtered brine with no mechanical deaeration	0.1

Table III — Analysis of Brine for Oxygen at Plant "B" Near Delaware, Okla.

Description of Sample	Mg Dissolved Oxygen per liter of Brine
Brine in pond at startup of plant	2.4
Filtered brine at startup	1.8 - 2.4
Filtered brine one week after inoculation with brine from Delaware "A" plant (No mechanical deaeration)	0.0

Table IV — Analysis of Brine for Oxygen at Plant Near Madill, Okla.

Description of Sample	Mg Dissolved Oxygen per liter of Brine
Brine before aeration	0.7
Brine after first aeration	1.5
Brine after second aeration	2.6
Brine in flocculation reactor	0.9
Brine after filtration with no mechanical deaeration	0.3

was about 0.005 in. penetration per year, and at Madill 0.003 in. per year. Nipples removed from service after seven to eight months showed no tuberculation or pitting, although they were coated with a thin layer of rust.

DISCUSSION

Oil field brines which are exposed to the air are commonly assumed to contain considerable amounts of dissolved oxygen. Thus Voss and Nordell[6] state "Aerated waters (brines) obviously are practically saturated with dissolved oxygen while waters which have been exposed to the atmosphere in open tanks or while flowing through troughs contain varying amounts (of dissolved oxygen)." The corrosiveness of brines containing dissolved oxygen is well recognized,[1,2] and for this reason brines are sometimes deaerated by means of vacuum or they are handled in closed systems to avoid contact with air.

The dissolved oxygen data obtained here indicate that such precautions may be unwarranted. At Delaware "A", for example, brine is pumped from a well into a pond where it is retained 6 to 12 hours. Next, the brine is (1) passed through a forced draft aerator, (2) kept in a tank while air is bubbled through it, (3) passed through another forced draft aerator, (4) treated in a sludge contact reactor, and (5) filtered. In spite of repeated, intimate and thorough aeration, the filtered brine is found to be substantially free of oxygen (Table II).

In the second case, Delaware "B", the plant was started up several years after Delaware "A". Brine is lifted from a well, passed through an aeration tower to remove H_2S, then passed through an open trough to a pond where it is retained about one day. Then the brine is passed through a sludge reactor and is filtered.

When this plant was placed in operation, dissolved oxygen determinations revealed as high as 2.4 mg of oxygen per liter in the final treated brine (Table III). The presence of oxygen was surprising because the plants at both Delaware "A" and "B" take brine from the same limestone formation and are only a few miles apart. After the discovery of oxygen at Delaware "B", it was decided to try to "seed" the Delaware "B" brine with a little of the oxygen-free brine of Delaware "A". This was done with the possibility in mind that the oxygen at Delaware "A" is consumed by biochemical action. Two weeks after the startup of the Delaware "B" plant, a truckload of 12 bbl of Delaware "A" brine was dumped into the pond of Delaware "B". Dissolved oxygen determinations, made one week after this "inoculation," showed that the oxygen concentration in final treated brine had dropped to zero.

In the third case, at Madill, the brine is aerated and kept in an open tank for three days. Here, after this long exposure to air, the brine is found to be almost free of oxygen (Table IV). Corrosion tests here and at Delaware "A" show that the oxygen concentration in the plant effluents has been reduced to a low figure.

While sufficient work has not yet been done to tell what happens to the oxygen at these plants, certain information is known. The disappearance cannot be attributed to reduction by ferrous iron or by hydrogen sulfide. Iron is low or absent in the injection brines before aeration, as shown in Table I. Hydrogen sulfide is removed very easily in all plants by aeration. After aeration, hydrogen sulfide is absent but dissolved oxygen is present, at first in appreciable concentrations, and eventually in practically zero concentrations. It is likely that the observed decrease in dissolved oxygen concentration is caused by biochemical action. For example, methane-containing waters have been known to consume oxygen through the action of *bacterium methanamonas*. The reaction is supposed to proceed in the following manner:[5]

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

This or a similar biochemical mechanism would account for the interesting decrease in dissolved oxygen at Delware "B" plant within one week after inoculation with oxygen-free water from Delaware "A."

Regardless of the mechanism of oxygen consumption in the brines, the fact remains that mechanical deaeration may not always be necessary in order to insure low corrosion rates. From the work described here, the need for careful dissolved oxygen analysis in each brine treating plant is apparent.

Table V — Results of Corrosion Tests in Brine Effluent From Plant "A" Near Delaware, Okla.

Test Nipple No.*	Penetration Rate, In. per Year, During 8-Month Period
1	0.0045
2	0.0057
3	0.0056
4	0.0043
5	0.0057
6	0.0045
7	0.0050
8	0.0059
9	0.0038
Average	0.0045

*Test nipples were distributed throughout brine injection system.

Table VI — Results of Corrosion Tests in Brine Effluent From Plant Near Madill, Okla.

Test Nipple No.*	Penetration Rate, In. per Year, During 8-Month Period
1	0.0015
2	0.0013
3	0.0023
4	0.0022
5	0.0037
6	0.0017
7	0.0036
8	0.0025
Average	0.0028

*Nipples were distributed throughout brine disposal system.

ACKNOWLEDGMENT

It is a pleasure to acknowledge the assistance and cooperation of the Pure Oil Co. field engineers who helped to make this study possible.

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DISCUSSION

By Paul G. Carpenter, Phillips Petroleum Co., Bartlesville, Okla., Member AIME

The authors have contributed a very urgently needed analytical technique which should aid materially in the successful operation of water floods.

We have had considerable experience with a modified instrument of this type during the past year and find that it performs in general as is described in the paper.

Analyses contained in Tables I and IV show that brine from the supply well at Plant "A" contains both hydrogen sulfide and oxygen. Have the authors made any study of the reaction rate between hydrogen sulfide and oxygen?

We would like to thank the authors and the Pure Oil Co. for making available to the industry this valuable analytical tool.

DISCUSSION

By L. C. Case, Gulf Oil Corp., Tulsa, Okla.

The observations relative to the permanence of oxygen in brines are of especial interest and significance. As a result of these findings it might be concluded that much existing equipment, for the purpose of preventing air entry into brine disposal systems, will shortly be found unnecessary. It should be kept in mind, however, that in many cases air exclusion is necessary from the standpoint of scale prevention.

A great many previous conclusions concerning the existence of oxygen in brines and its effects on equipment may now be open to question. For example, I recall a field experiment wherein oxygenated fresh water was added to a well annulus and the well effluent tested for oxygen. When no oxygen was found at the wellhead, it was concluded, perhaps erroneously, that it disappeared via the corrosion process. The authors have given us promise of early solution to similar problems where corrosion, although not definitely known, must be assumed at considerable cost in preventive measures. ★ ★ ★

THE DELTA-LOG, A DIFFERENTIAL TEMPERATURE SURVEYING METHOD

R. B. BASHAM AND C. W. MACUNE, WESTRONICS, INC., FORT WORTH, TEX.

ABSTRACT

Very small anomalies in oil well temperatures are detected and measured by recording the difference in temperature existing between two thermally sensitive elements which are spaced several feet apart on a small diameter carrier and lowered into the bore hole. The elements operate in a balanced electrical circuit, sending only a reference signal to the surface as long as normal gradient temperatures are encountered. When either element enters a temperature disturbance, the circuit is unbalanced and produces large recorder deflections for minute anomalies. The system is highly sensitive to small changes in thermal gradients caused by gas or fluid movements and to the boundaries between beds of different thermal conductivities. Typical logs show successful applications of the process to locating gas and water leaks in casing, gas entry, and gas-oil contact.

INTRODUCTION

Temperature measurements in oil wells have been made for many years in the search for additional sub-surface data. It has been generally agreed that many conditions in the bore hole cause temperature anomalies which, if located and measured, could yield useful information. But it has been recognized also that many of the irregularities, such as those produced by small water and gas leaks in casing, might be very small and therefore difficult to detect with certainty.[1] Although temperature measurements have been made which show anomalies of less than one degree deviation from normal gradient temperatures, the results are usually uncertain and unconvincing. The general practice, therefore, has been to apply temperature surveys only to well conditions known to produce appreciable disturbances, such as large gas movements and cement hydration.

The recent demand for additional data has focused attention on the problem of making dependable temperature measurements in the many instances when anomalies are small but none the less significant. It was for the purpose of detecting these minute irregularities in bore hole temperature that the program described in the following text was undertaken.

It is emphasized that this presentation is not offered as a complete study, for the process is still partially experimental. But it is believed that the results obtained thus far will be of interest to the industry and will indicate some of the system's potential usefulness.

DIFFERENTIAL MEASUREMENT

The chief value of differential measurement lies in the fact that a difference between two factors can be measured with a scale of values best suited to that difference, a scale that might be cumbersome or impractical if applied to the factors themselves. When it is known that all factors will be nearly equal in value, and therefore the differences consistently small, it is possible to select a scale which will permit very accurate measurement of the differences.

This advantage is in contrast to the difficulty of measuring small increments of a single variable, where the increment must be measured by a large scale which is suitable for measuring the entire factor. Gradient temperatures are usually measured under this latter condition where temperature measuring apparatus must have a scale extending over the range of expected temperatures, say 50° to 250°F, and it becomes almost impossible to detect small irregularities of less than one degree. The use of large strip chart recorders and divided multiple ranges tend to amplify the small anomaly and make it more pronounced. But the instability of instruments, both

[1]References given at end of paper.

Manuscript received in the office of the Petroleum Branch Sept. 10, 1951. Paper presented at the Petroleum Branch Fall Meeting in Oklahoma City, Okla., Oct. 3-5, 1951.

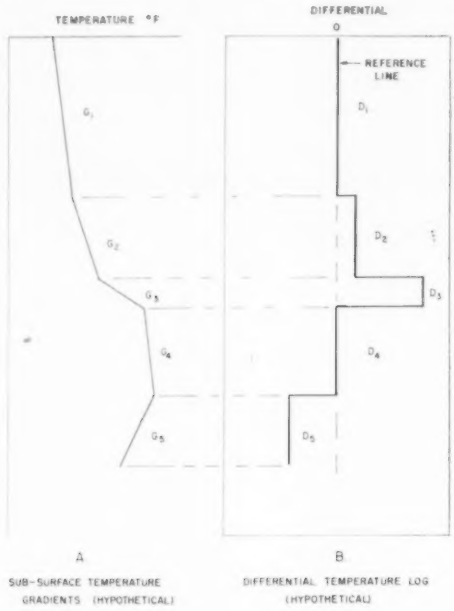

FIG. 1 — APPLICATION OF DIFFERENTIAL MEASUREMENT TO SUB-SURFACE TEMPERATURE GRADIENTS.

electrical and mechanical, limits the efforts in this direction and much of the disadvantage of measuring the increment in terms of the total range remains.

Another important characteristic of the differential system is its tendency to respond only passively to normal conditions encountered in the measuring process, such as when the factors being compared are all equal in value, but to respond actively to the abnormal or unequalized condition, thus emphasizing the abnormal in its measurements.

DIFFERENTIAL TEMPERATURE MEASUREMENT IN THE BORE HOLE

Since the chief interest in temperature surveys usually centers on the irregularities and deviations from the normal gradient temperatures, it appeared that the differential type of measurement would be useful in spotlighting those points of interest. Some of the considerations in the application of this system to bore hole temperatures are reviewed in the following section.

Two thermometers spaced several feet apart in the bore hole will read essentially the same temperature; but since the geothermal gradient produces an increase of approximately one degree for each 60 ft of traverse downward, the lower thermometer will be slightly warmer than the upper.[3] If the thermometers are spaced six ft apart, the lower one will be 0.1° warmer. As the two thermometers move slowly downward, they will both increase in temperature as determined by the depth, but will maintain the 0.1° difference as long as the gradient is constant. For each value of gradient there is a fixed difference in the readings of the two thermometers. And it is evident that a record of this difference on a strip chart will be a straight vertical line for each value of the gradient, as shown in Fig. 1-B, with displacement from a reference line being proportional to the value of the gradient at any given depth.

This reference line can be established at the "zero" gradient level, the condition where both thermometers are at the same temperature when placed side by side just below the surface. However, it is more practical to take the gradient measured by the spaced thermometers at some point approximately 100 ft below the surface as a prime reference to which all other gradients below or above will be compared.

It should be noted that the recorded difference in thermometer readings is essentially a mathematical first derivative of the geothermal gradient curve. The derivative of a straight line function having the slope G_2 in Fig. 1-A is a constant, and it is represented numerically by the displacement of the recorded line D_2 from the reference line in Fig. 1-B. Since the differential recording has the character of a first derivative, it will change value abruptly at points where the temperature gradient changes slope; and the recorded line will be displaced abruptly the full amount corresponding to the new gradient.

This characteristic enables the differential measuring system to detect and magnify the small disturbances and irregularities in bore hole temperatures. When the lower thermometer enters an area cooled locally by gas escaping from a casing leak, it

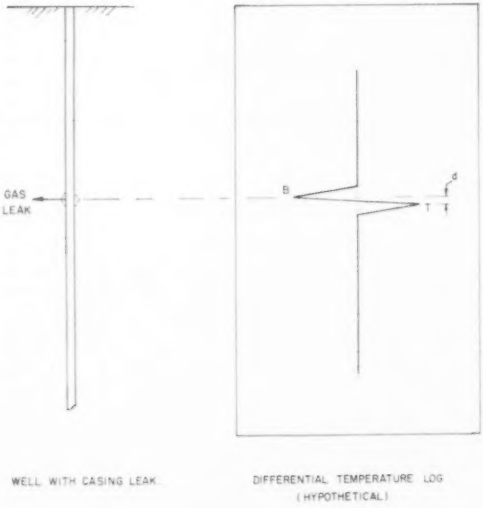

FIG. 2 — THEORETICAL APPLICATION OF DIFFERENTIAL TEMPERATURE SURVEY TO LOCATION OF CASING LEAK.

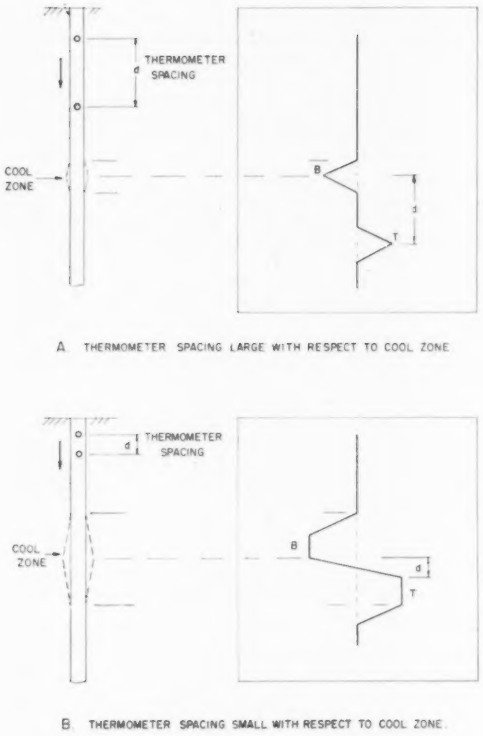

FIG. 3 — INFLUENCE OF THERMOMETER SPACING ON APPEARANCE OF DIFFERENTIAL TEMPERATURE LOG.

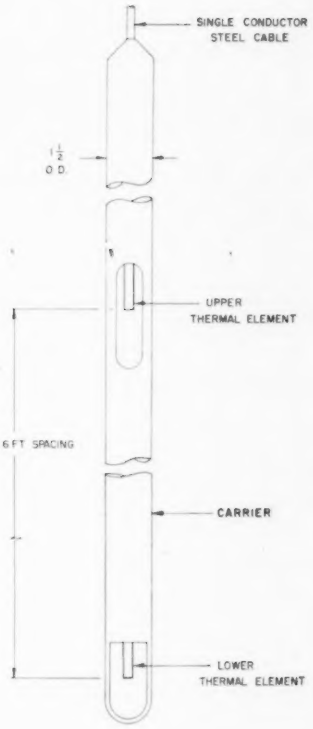

FIG. 4 — CARRIER AND THERMAL ELEMENTS USED IN DELTA-LOG TEMPERATURE SURVEY.

establishes a negative differential with respect to the reference, and the recorded trace moves abruptly to the negative side of the reference line, as shown in Fig. 2. Point *B* represents the maximum differential measured as the lower thermometer passes the leak point. Having passed the point of maximum cooling, the lower thermometer moves into warmer fluid and therefore the negative differential diminishes until it returns to the reference line, at which point the thermometers are straddling the leak point. Continuing the traverse downward, the lower thermometer has returned to fluids of normal temperature as the upper thermometer enters the cooled area. Then the lower thermometer, though at normal temperature, appears to be relatively much warmer than the upper, and a positive differential is recorded, peaking at Point *T* when the upper thermometer passes the leak point. The interval *d* is the thermometer spacing.

The spacing between thermometers has considerable influence on the form of the differential recording. When the separation is large with respect to the cooled area, the peak *B* and *T* are widely spaced, as in Fig. 3-A; and with the spacing small in comparison to the cooled zone these peaks become flattened plateaus, as in Fig. 3-B.

EQUIPMENT

Differential temperature surveys have been run for the past year using equipment which functions in the manner just described. Recordings of temperature anomalies agree essentially with the results which could be predicted from a straightforward analysis of the two thermometer action.

The thermometers used are a special type of thermally sensitive elements of the electrical resistance type developed specifically for this application. Each element is enclosed in a slender steel tube to prevent contamination from well fluids and the two elements are spaced six ft apart on a carrier tube 1½ in. in diameter, with the lower element caged at the bottom end and the upper element housed in a slotted chamber in the body of the tube. Fig. 4 illustrates this arrangement. Simplicity of the electrical circuit requires that very few electrical components be included in the sub-surface equipment. As a result, the carrier tube serves principally to support and space the thermal elements and to provide weight when the tube is lowered into the well.

Electrical equipment on the surface consists of voltage regulated power supplies both AC and DC, precision resistance

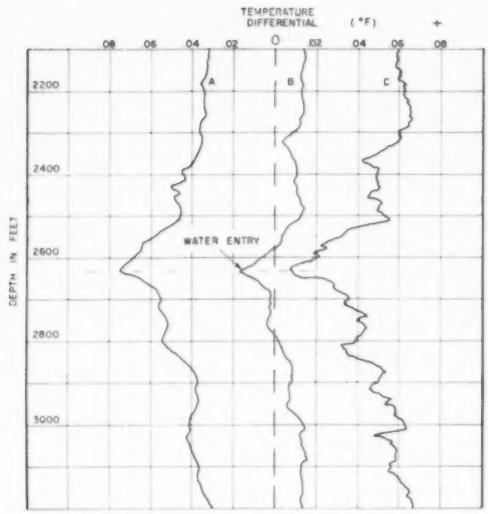

FIG. 5 — SAMPLE DELTA-LOG SHOWING LOCATION OF WATER LEAK IN CASING.

bridge circuits, balancing and sensitivity controls, and an electronic strip chart recorder. When simultaneous logs of both gradient and differential temperatures are run, it is necessary to use a dual recorder.

Hoisting equipment installed in the instrument truck provides speeds of 15 to 500 ft/min in the single conductor steel armored cable supporting the sub-surface equipment.

Since the differential survey is made with the carrier and elements in continuous rather than in point to point movement, it is necessary to reduce thermal lag in the sensing elements to a minimum. This is accomplished by (1) using very small thermal elements having little mass, (2) separating the elements from well fluids by a thin, highly conductive window for maximum heat transfer, and (3) isolating the elements thermally from the conducted heat of the carrier body.

High sensitivity and stability in the system are largely a result of the characteristics of the thermal elements and associated circuits. The electrical circuits make a null-type measurement in which a potential between the thermal elements is balanced automatically by a potential in the surface equipment, with little current flow involved; therefore changes in line resistance have no effect on the measurements.

PROCEDURE

In general the procedure in conducting a differential temperature survey follows the familiar pattern of other well logging operations.

The first step in all cases requires that a prime reference gradient be determined by holding the sub-surface tool at approximately 100 ft below the surface for 15 minutes if in fluid and longer if above fluid. Temperatures at that level are considered to be free of diurnal and annual variations.[2] Observations of the electrical instruments will determine when thermal equilibrium is attained, and the recorder pen is set at center scale on the strip chart for that condition. When points of interest are located, it is common practice to detail those limited areas by establishing a new reference gradient at center scale immediately above the area and then operating the equipment at higher sensitivity.

Logging is usually performed on the downward traverse so that the well fluids are encountered in their state without being previously disturbed by passage of the carrier and wire line.

Logging speeds generally fall in the range of 50 to 100 ft/min. It has been determined by field test that logs made at slower speeds produce little more detail of significance, whereas logs made at speeds greater than 100 ft/min begin to suffer some loss of detail and amplitude in the recorded anomalies.

On the initial logging run, the selection of a proper sensitivity setting which will keep the recorder on scale and avoid resets is a matter of estimate. The usual practice is to select a low sensitivity setting for an exploratory log which will locate the major anomalies and serve as a guide for succeeding runs at higher sensitivities.

TEMPERATURE SENSITIVITY

Differences in temperature between the two thermal elements are recorded on a scale of .02° per in., and therefore differences of .001° can be detected. It is this high sensitivity which opens up a new range of bore hole temperature measurements which might be described as "microscopic." Field examples shown in the following section were logged at this sensitivity, and examination of the logs (Figs. 5, 6 and 7) will show that full scale recorder deflection from the center reference line is produced by a difference of only 0.1° between the thermal elements. Therefore, small anomalies which are not perceptible to conventional sub-surface thermometers can produce full scale deflections on the differential temperature log.

It should be recognized that the amplitude of an anomaly as recorded on the differential temperature log does not necessarily represent quantitatively the total change in local temperatures occurring at the point of the anomaly. The differential log is a record only of the difference in temperature existing between the two thermal elements at any point in the bore hole.

FIELD EXAMPLES

Some representative logs made in the Permian Basin of West Texas are offered to illustrate the application of the differential survey to well conditions which are known to create temperature anomalies. The principles of interpretation are by no means complete on this process and no effort will be made to analyze all portions of the curves shown. It is believed, however, that the basic principle of the differential measurement is well demonstrated by the examples, and the conditions which brought about the surveys are conspicuously prominent in each case.

In the reproduction of the logs having several curves from successive logging runs, the curves were arbitrarily offset from the reference line for the sake of clarity.

Location of Water Leak in Casing

The three curves *A*, *B* and *C* in Fig. 5 are successive runs made to locate the point of water entry into casing. A few bailer runs lowered the fluid level slightly prior to the survey to upset pressure equilibrium and accelerate water entry through the casing leak, and during two hours between runs *A* and *C* the fluid top rose 70 ft in the seven-in. diameter casing. Runs *A* and *B* were made under similar conditions and both indicate water entry at the depth where the differential curve changed from increasingly negative values on the downward traverse to increasingly positive values. With an average water flow of approximately one gal/min the anomaly was small and therefore the sensitivity necessary to make it appear on the log also amplified other temperature variations in proportion, some of which are in the same order of magnitude as the leak anomaly. Although the negative slope down to the leak and the positive slope below it served to locate the leak point, it was further substantiated by the correlation of the breaks at 2,637 ft on three successive curves and the lack of correlation among the other temperature variations. Curves *A* and *B* were logged at 100 ft/min, and *C* was run at a slower rate of 50 ft/min, with a resulting increase in detail or showing of minor anomalies. A casing caliper survey later verified this indicated leak point by finding a 20-in. casing split at 2,637 ft.

Locating Gas Leaks in Casing

The expansion of gas at a casing leak produces much greater temperature anomalies in general than water entry and makes the gas leak more simple to locate. Fig. 6 shows the correlation of two prominent kicks on successive runs made two hours apart, with curve *B* logged at lower sensitivity than *A*. Gas from the leak was allowed to accumulate between the oil casing string and the salt string for 24 hours before the survey; then it was bled off and allowed to flow during the survey in order to create maximum gas movement through the leak. The sub-surface equipment was lowered into the tubing which was shut off under 700 lb pressure. The sharpness and amplitude of the breaks in the log at 1,275 ft make the location of the leak at that point fairly definite, and squeeze cementing at that level later shut off the flow of gas into the salt string and put the well back in production.

Location of Gas Producing Zone

Similarly the expansion of gas emerging from a producing formation into the bore hole creates a relatively cool zone. Fig. 7 shows a determination of such a zone in a well producing at a gas/oil ratio of 5,000. After a 24-hour shut-in period the well was allowed to flow for three hours from the seven-in. casing at 400 lb pressure. Casing was set at 3,147 ft and tubing at 3,265 ft. The gas entry anomaly was detected at 3,185 ft by the carrier and elements lowered in the tubing. Curve *A* was run at full sensitivity and *B* and *C* were made at a lower sensitivity, as indicated by their reduced amplitudes. However, the correlation of the sharp breaks on the three successive logs at the same depth is strong evidence that gas entry was occurring at that point.

It appears likely that the sharp break to the right side of the log immediately below the gas entry indicates the top of the oil producing zone, but no verification has been made to date in support of this theory.

In this instance the reference gradient was established at 3,000 ft rather than near the surface, because the approximate location of the producing zone was known; and starting the log at center scale near the anomaly permitted surveying the area at a higher sensitivity than might have been possible otherwise.

Prior to the differential log a self-contained recording thermometer of the conventional type was run in the well to locate this gas zone, and it failed to indicate any anomaly.

OTHER APPLICATIONS

Full appreciation of the temperature sensitivity offered by the differential survey and analysis of the results obtained in the field examples presented suggest other uses for the system, and several investigations are currently in progress to explore its potential. Some of the additional applications are:

1. Old Cement. General practice requires that the top of cement be located by conventional temperature gradient measurements within 72 hours after a cementing operation is completed, for most of the heat released by the exothermic reaction of hardening cement will be dissipated in that period. But the reaction continues at a reduced rate over an extensive

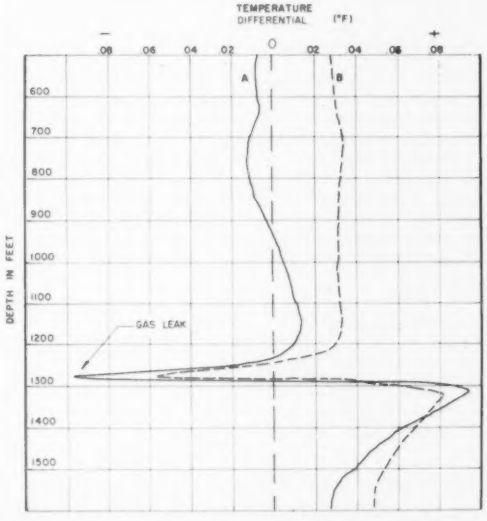

FIG. 6 — SAMPLE DELTA-LOG SHOWING LOCATION OF GAS LEAK IN CASING.

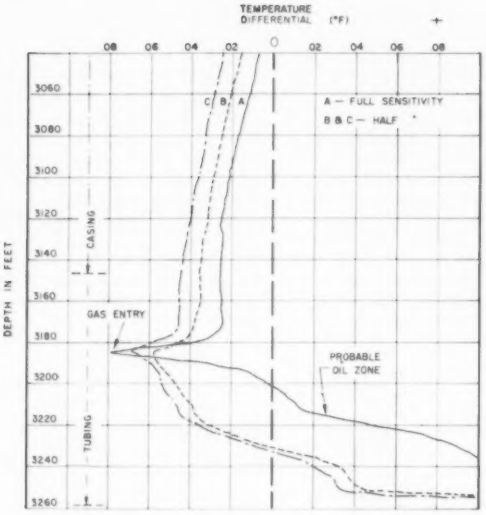

FIG. 7—SAMPLE DELTA-LOG SHOWING LOCATION OF GAS-PRODUCING ZONE AND PROBABLE OIL ZONE.

period, and it is possible that current field tests will determine that the sensitive differential measurements are capable of detecting residual heat in cement several weeks after the initial set.

2. Permeable Zones. Formations capable of absorbing fluid pumped down the bore hole can be located by the relative disturbance of normal temperature gradients above and below a permeable zone. The fluid, being at surface temperature and somewhat cooler than the formations it traverses, lowers the normal temperatures down to the point where it enters the formation. Below this point the gradient remains more nearly normal, and the boundary is clearly marked by a difference in temperature which is proportional to the per cent of the total fluid flow absorbed by the formation. Recent test well results showed that the system is sensitive to a flow of a small fraction of a gallon per minute leaving the fluid column.

3. Lost Circulation. Operating on the same principle used in detecting permeable zones, the system should be useful in locating points at which circulation of drilling fluid is lost. The quantity of fluids moving into the thief zones and the relative temperature between the fluid and formations are widely varying factors, but it is reasonable to suppose that an anomaly large enough to be detected will usually exist when sufficient circulation is lost to be considered a problem.

4. Formation Logging. Correlation of differential temperature logs with electric logs indicates that the former will record anomalies characteristic of the various formations, their heat capacities and conductivities in particular. It is generally recognized and previous measurements have shown that the heat conductivities of the various sedimentary beds differ widely, and it is this difference between beds which alters the flow of heat from the earth's center toward the surface. Each formation transmits heat at a particular rate and has a characteristic geothermal gradient which is determined by its composition, compaction, and fluid content.[2] In view of the high sensitivity discussed in previous sections, it is possible that the differential survey will offer significant results in the identification of formations.

CONCLUSIONS

The differential temperature logging system, because of its high sensitivity to small temperature changes, opens up a new phase in the search for sub-surface information. Numerous well conditions which are known to cause temperature disturbances too small to be measured by conventional means can now be explored thermally. Field examples demonstrate the system to be effective, and the results are consistent with theory. Experience in interpretation of the logs and continued exploration of its potential applications will determine the full extent of its usefulness.

ACKNOWLEDGMENTS

The authors wish to thank Westronics, Inc., for permission to write this article and Worth Well Surveys, Inc., for the data supplied from test and field operations. The cooperation and interest of many friends in Welex Jet Services, Inc., and the Chemical Process Co. are also greatly appreciated.

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OBSERVATIONS FROM PROFILE LOGS OF WATER INJECTION WELLS

H. H. KAVELER, MEMBER AIME, AND Z. Z. HUNTER, PHILLIPS PETROLEUM CO., BARTLESVILLE, OKLA.

ABSTRACT

Variation of the horizontal permeability (parallel to the bedding plane) in the vertical section of reservoir rocks has long been observed as a characteristic of a normally heterogeneous system which reservoir rock represent.

The use of a recently developed water injection profile device offered opportunity to measure with a high degree of reliability the rate of inflow of water into Burbank sandstone in wells previously cored. Water injection profiles were not correlative with core permeability profiles in such wells. Apparently the vertical permeability substantially influences the flow between strata in a formation in a manner as to void the usual conclusions that have been drawn from consideration of the horizontal permeability measurements alone. The results obtained in comparing water injection profiles with horizontal permeability profiles suggest that many of the usual production operations based upon "selective" behavior or treatment of rock exposed in well bores need to be re-valuated and re-examined.

INTRODUCTION

Petroleum reservoir rock are heterogeneous systems. Heterogeneity exists in respect to lithologic character insofar as such rock are composed of distinguishable solid phases. Heterogeneity also exists in respect to certain properties, such as porosity and permeability, that vary due to variation of the physical structure of the rock. Except in exceptional cases, both the horizontal permeability (measured parallel to the bedding planes) and the vertical permeability (measured perpendicularly to the bedding planes) exhibit significant variation in any common source of supply. The variation in horizontal permeability, as reflected by core analyses, has drawn the greatest attention of petroleum technologists probably out of the general notion that the mass movement of fluids in a reservoir is predimonantly in the horizontal direction. Furthermore, in the usual case, the rock permeability measured in the horizontal direction is greater than that in the vertical.

The variation of horizontal permeability of reservoir rock has been the basis for developing a number of operating practices and procedures intended to improve the petroleum production operation. Many such procedures are referred to as "selective" in the sense that the practice is intended to control the flow to a more, or less, permeable interval within the common source of supply. It is often said that such practices are "tailored" to the permeability profile. The practices referred to involve, among others, the following: selective perforation of casing; selective shooting, acidizing and plugging; plugging back to intervals of low permeability; and, regulation of flow to prevent coning of water or gas, or irregular encroachment of water or gas. Certain expressed notions involving a concept of "by-passing," or "trapping," that are held to be particularly harmful in causing the avoidable loss of recoverable petroleum have grown from observed variations in the horizontal permeability. Oftentimes estimates of the reserve of a common source of supply are tempered by conclusions relating variation in horizontal permeability to recoverability of the oil-in-place.

Certain conclusions attributed to the significance of the variation of the horizontal permeability often extend to the design and operation of pressure-maintenance projects involving both water flooding and gas-injection. Many advocate increasing the number of injection wells, advocate maintaining uniform and equidistant input-output well patterns, or advocate so-called "dispersed" gas-drive techniques rather than gas-cap injection because the permeability profile of cored wells is supposed to indicate that "by-passing" or "trapping" would otherwise exist.

It is important, therefore, to have an opportunity to test whether the variation in the horizontal permeability found through core analyses of a typical reservoir rock is sufficient to establish the paths of fluid flow in a reservoir. It is particularly important to have an opportunity to determine whether flow at the sand face of a well conforms to the permeability profile as established by core analyses. In that manner, the merit of certain so-called "selective" operating procedures and other notions may be evaluated. The purpose of this paper is to compare horizontal permeability profiles of wells in the Bartlesville (Burbank) sandstone with water injection profiles, for the purpose of showing that there is no correlation between the horizontal permeability of a core and the water intake characteristics of a typical sandstone.

GENERAL CHARACTERISTICS OF BARTLESVILLE (BURBANK) SANDSTONE

The Bartlesville sandstones of Northeastern Oklahoma are off-shore bar deposits.[1] Although other reservoirs had different processes associated with their deposition or with the formation of their porous, permeable structure, the Bartlesville sandstones on which these field tests were made are, in every respect, typical petroleum reservoir rock. The permeability of the Bartlesville sandstones shows a typical variation in both the horizontal and vertical direction. Furthermore, the permeability profile logs of wells in any pool are not correlative, even as between wells as close as 660 ft and 330 ft apart.[2,3] The same condition exists in such sandstones as the Jones Sand at Shuler[4] and is the ordinary and usual characteristic of reservoir rock.

THE FIELD DATA

The data reported herein are those obtained from coring of nine wells on the center of ten-acre locations for the purpose of providing water-injection wells in the Bartlesville (Burbank)

[1]References given at end of paper.

Manuscript received in the Petroleum Branch office Aug. 20, 1951. Paper presented at the Petroleum Branch Fall Meeting in Oklahoma City, Okla., Oct. 3-5, 1951.

sand of the North Burbank Field in Osage County, Oklahoma. Eight of the wells were cored by diamond bit and recovery was 100 per cent. The usual core analyses were made, including a permeability measurement on a plug taken from each foot of the 4½-in. diameter core. A typical core analysis reflecting porosity, permeability, oil saturation, water saturation and salinity is shown in Fig. 1. The cores were taken with a low-water-loss water-base mud.

Recently a flow profile device was developed[2] and used to obtain water-injection profiles of the nine wells. The profiling device was of such design as to provide measurements of more than ordinary reliability. The water-injection profiles were determined by repeated traverses carried on during a period of six hours, over which period of the time the measurements were found to be reproducible. The hydrostatic head at the sand face was determined by the use of a float. The water injected into the well during the course of the experiment was measured by means of a surface meter. All measurements were carried on under stabilized conditions. Filtered water, treated to prevent growth of bacteria and algae, is injected into these wells and, for that reason, plugging action arising from suspended solids could not account for any of the intake characteristics here reported.

Figs. 2 to 10, inclusive, are a comparison of the horizontal permeability profile of each of the nine wells with the water-injection profile. In some instances the change in injection profile over a period of one year is also shown.

Generally, the water was found entering the reservoir rock at points that were not correlative with the measured horizontal permeability of the sandstone.

The injection profile shown for Well 127-W-1 in Fig. 2, for example, at the rates of injection indicated, shows the water entering the rock mainly in the interval 2,933-2,937 ft. The core analyses showed permeability in this section of less than one millidarcy, but examination of the core itself showed evidence of vertical fracturing in the interval 2,935-2,940 ft. Later injection profiles indicated the water entering the formation above the fractured zone at 2,926-2,934 ft.

Fig. 3 shows the injectivity profile for Well 127-W-2. The most permeable section in this well is 2,917-2,922 ft. Permeabilities were measured as high as 288 md at the top of this interval. The profile made in April, 1950, after 25,000 bbl of water had been injected showed the main flow to be in sections above and below this point and, more particularly, in the next most permeable interval, 2,883-2,892 ft. In January, 1951, a second profile was run when the cumulated water injection was approximately 252,000 bbl. The principal inflow was observed to be in the interval 2,930-2,936 ft, which was taking 495 bbl of the 605 bbl being injected per day. In March, 1951, another profile was run after approximately 46,000 bbl of additional water had been injected.

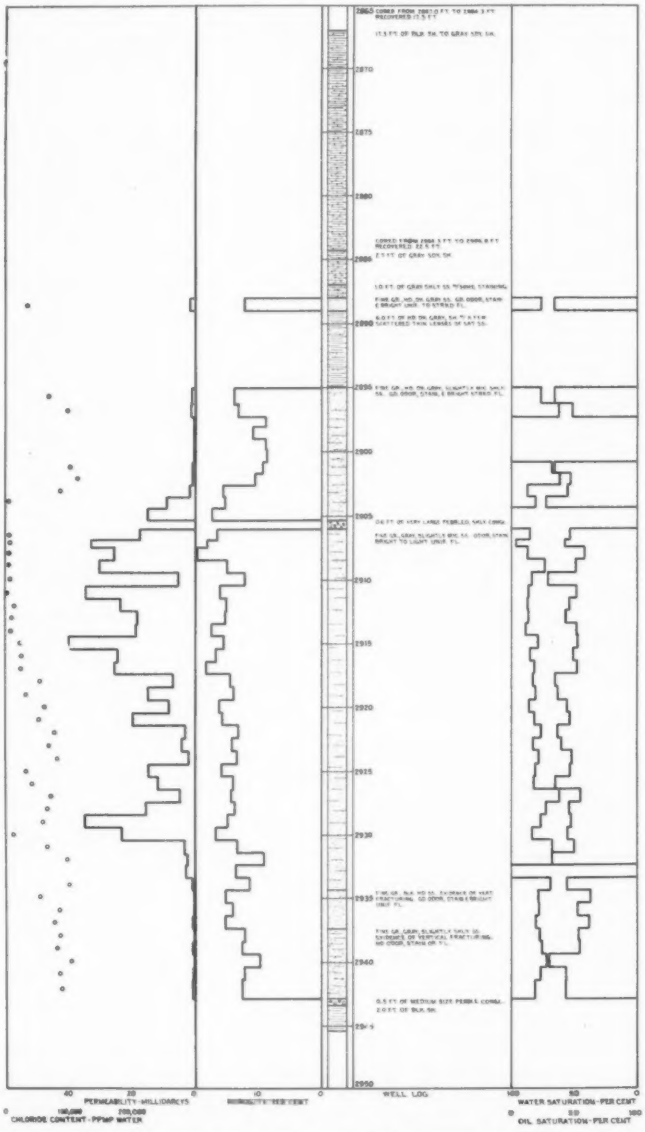


FIG. 1 — ANALYSIS OF CORE FROM NORTH BURBANK UNIT 127-WI SW/4 SEC. 16-26N-6E, OSAGE COUNTY, OKLA.

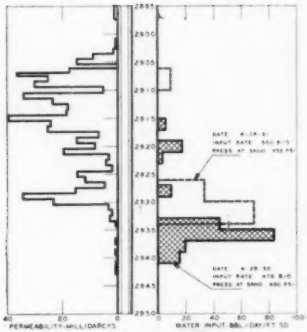


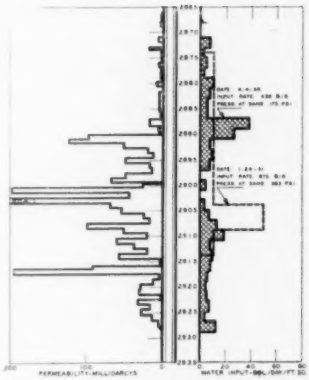
FIG. 2 — PERMEABILITY AND WATER INJECTIVITY LOGS, NBU 127-W-1.

and the interval 2,930-2,938 ft was found to continue to be taking disproportionately large quantities of water. The core description from this well revealed a tight section of sand and conglomerate with vertical fractures from 2,937-2,941 ft, and the conclusion was that the fractured conglomerate section was a "thief" horizon. Accordingly, a cement plug was set on March 22, 1951, with a top at 2,934 ft. In April, 1951, a profile log was run as shown in Fig. 3, with a high rate of influx indicated for the interval 2,925-2 928 ft. The intake capacity of the well was not decreased as a result of setting the cement plug in the zone of fracturing, nor was the injection profile of the well substantially altered. Undoubtedly, the flow into the fractured zone still continues.

Fig. 4 shows that the intake capacity of the sandstone in Well 127-W-3 was quite uniform over the entire section in April, 1950, in spite of wide variation in horizontal permeability; but the log taken in January, 1951, shows one section of the sand to be substantially increased in daily rate of intake. Fig. 5 for Well 127-W-4 shows on the first survey in August, 1950, a relatively uniform distribution of intake through the section, but in March, 1951, after approximately 314,000 bbl of water had been injected, a significant change in profile characteristics had occurred with the lower section taking a relatively large percentage of the total input. The core showed no fracturing or unusual conditions in the interval 2,970-2,975 ft.

Fig. 6 for Well 127-W-5 is of particular interest because the water inflow is almost entirely into those sections shown by the core analyses to be less permeable and because the section from 2,989-2,994 ft was shown by core inspection to contain vertical fractures. In this instance, there was no inflow into a fractured section.

In Figs. 7 and 8 for Wells 127-W-6 and 127-W-7 there was again no consistent relationship between intake capacity and horizontal permeability, and in the instance of Fig. 9, even though Well 127-W-8 was found to have a fractured conglomerate at the base of the Burbank Sand from 2,990-2,991 ft., this section was found to have no intake capacity. Finally, in Fig. 10, even though the interval 2,967-2,979 ft in Well 127-W-9 exhibited on the basis of



F.G. 4 — PERMEABILITY AND WATER INJECTIVITY LOGS, NBU 127-W-3.

core data the large fraction of the millidarcy-feet capacity, the water influx was comparatively uniform throughout the section.

A GENERAL CONCLUSION

The lack of correlation between permeability and flow at the sand face of wells is not due to conditions peculiar to this reservoir. What has been observed in this instance is likely to be found in all other reservoir rock with few exceptions. It may be concluded, therefore, that the core permeability measurements for any well will not serve as the basis for predicting the fluid flow characteristics of any particular interval in a productive section. The change in injection profile with time further indicates that flow changes within the body of the rock are occurring so that the permeability profile or the water-injection profile do not reflect even approximately the flow through any stratum of the entire reservoir. The lack of correlation between the profiles is of such magnitude as to require explanation by consideration of other than effective permeability relationships arising from variation in fluid saturation of the rock.

THE IMPORTANCE OF VERTICAL PERMEABILITY

If flow in a reservoir were strictly in the horizontal direction parallel to the bedding planes, flow would be through "series conductors" of varying permeability. This is readily confirmed by such observations as were made on the 4½-in. cores taken from the Bartlesville

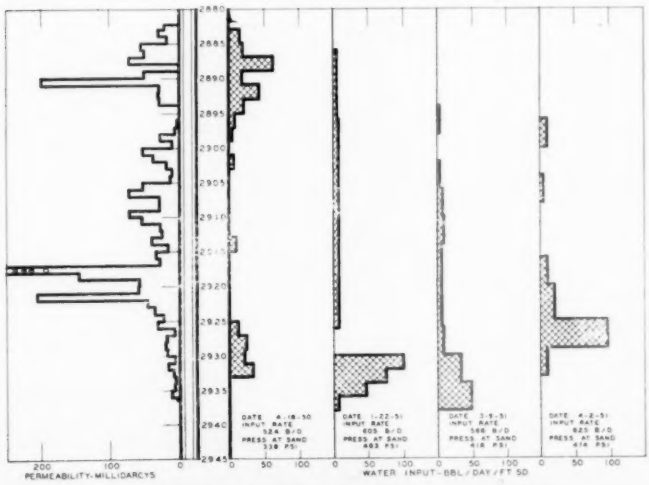


FIG. 3 — PERMEABILITY AND WATER INJECTIVITY LOGS, NBU 127-W-2.

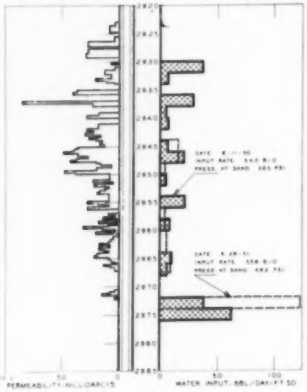


FIG. 5 — PERMEABILITY AND WATER INJECTIVITY LOGS, NBU 127-W-4.

(Burbank) sandstone. A permeability plug was cut parallel to bedding planes and broken into three pieces of equal length, and permeabilities were run on each piece. The horizontal permeability showed variation of as much as 300 per cent between adjacent pieces with no regularity in value between the pieces taken from the center of the core or from either side. Over distances as short as 4½ in. there is marked variation in horizontal permeability. This alone would account for the lack of correlation between the horizontal permeability profile and the water-injection profile of a well and might substantially account for the variation of the injection profile with time as the reservoir fills up and the water moves through horizontal strata into sections of higher or lower permeability.

But, in addition, the vertical permeability must influence the path of flow of fluids through the rock and have its effect also in establishing intake capacity different from that expected from the horizontal permeability profile established by core analyses. The Burbank sands are typical in respect to the fact that the vertical permeability has values as high as 50 per cent of the horizontal permeability and show wide variation. Nevertheless, the fact that the area through which vertical flow may

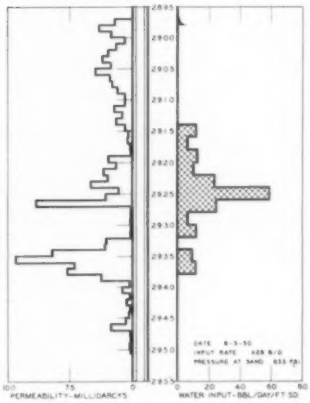


FIG. 7 — PERMEABILITY AND WATER INJECTIVITY LOGS, NBU 127-W-6.

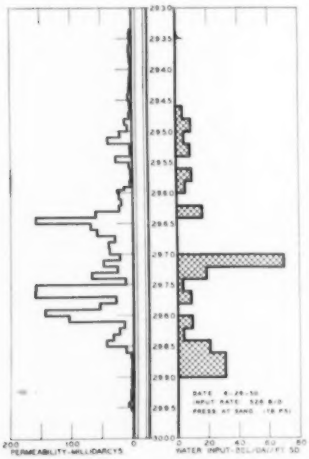


FIG. 6 — PERMEABILITY AND WATER INJECTIVITY LOGS, NBU 127-W-5.

occur in a reservoir increases as the square of the radius outward from the injection well (or producing well) results in a condition whereby a substantial part of the fluid passing the sand face in the well-bore could move through vertical paths even though the permeability in that direction is relatively low. As a consequence, flow through the bulk of the reservoir rock must be a meandering flow such as would be expected in a radial system. Actually, the potential field and the corresponding lines of flow constitute a complex of meandering paths defined by the "composite" permeability arising from the existing values of the horizontal and vertical components from point to point. The influence of vertical permeability would be to remove the horizontal permeability as the sole criterion of flow at the face of the sand and, for that reason, one would not expect flow at the sand face to be correlative with the horizontal permeability. One of the interesting investigations that might be carried out, using a proper analog, would be to study the composite permeability of a network of conductors arranged so as to represent various combinations of horizontal and vertical permeability components. Such a study, even though carried on under idealized conditions, would serve to interpret the significance of the permeabilities measured on cores in the horizontal direction.

CONCLUSIONS APPLYING TO PRODUCTION PRACTICE

The principle conclusion that comes from the studies herein reported is that most of the practices employing the principle of "selective" control of the flow of fluids at the face of the sand in a well need to be re-examined. It appears doubtful that the operations tailored after the horizontal permeability profile have a sound basis. The horizontal permeability of cores does not measure relatively the flow at the sand face of a productive section. In a similar fashion the concept of "by-passing" based upon observed variations in horizontal permeability needs to be re-examined, particularly in connection with pressure maintenance operations. Eliminating obviously "thief" horizons lying within or immediately adjacent to a common source of supply, and eliminat-

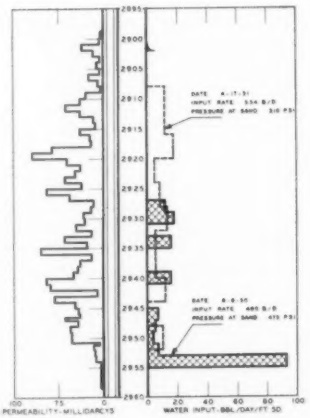
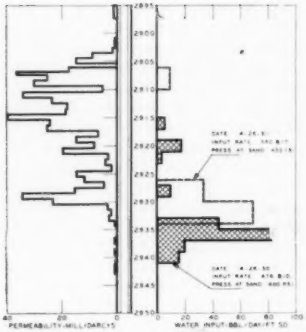


FIG. 8 — PERMEABILITY AND WATER INJECTIVITY LOGS, NBU 127-W-7.



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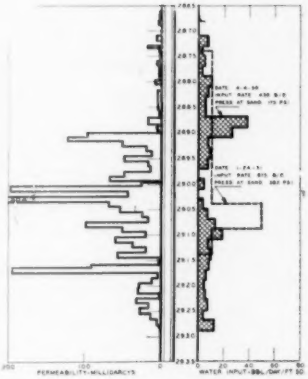

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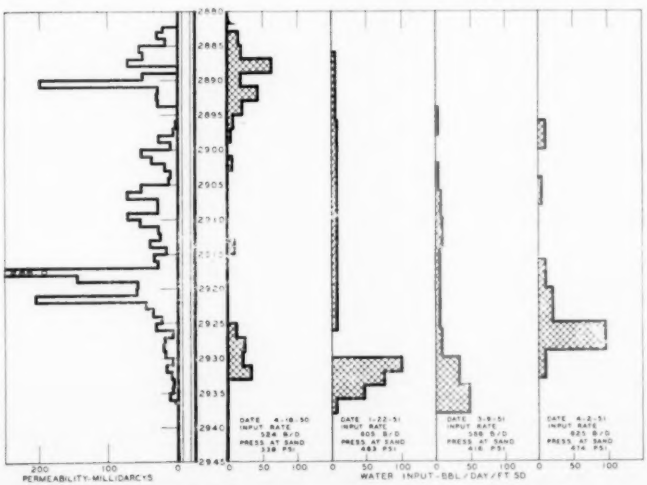

FIG. 3 — PERMEABILITY AND WATER INJECTIVITY LOGS, NBU 127-W-2.

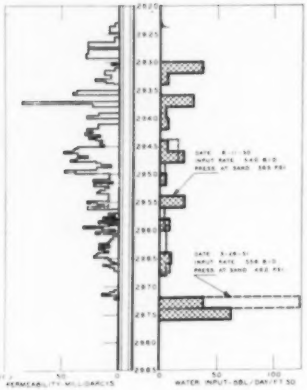

FIG. 5 — PERMEABILITY AND WATER INJECTIVITY LOGS, NBU 127-W-4.

(Burbank) sandstone. A permeability plug was cut parallel to bedding planes and broken into three pieces of equal length, and permeabilities were run on each piece. The horizontal permeability showed variation of as much as 300 per cent between adjacent pieces with no regularity in value between the pieces taken from the center of the core or from either side. Over distances as short as 4½ in. there is marked variation in horizontal permeability. This alone would account for the lack of correlation between the horizontal permeability profile and the water-injection profile of a well and might substantially account for the variation of the injection profile with time as the reservoir fills up and the water moves through horizontal strata into sections of higher or lower permeability.

But, in addition, the vertical permeability must influence the path of flow of fluids through the rock and have its effect also in establishing intake capacity different from that expected from the horizontal permeability profile established by core analyses. The Burbank sands are typical in respect to the fact that the vertical permeability has values as high as 50 per cent of the horizontal permeability and show wide variation. Nevertheless, the fact that the area through which vertical flow may occur in a reservoir increases as the square of the radius outward from the injection well (or producing well) results in a condition whereby a substantial part of the fluid passing the sand face in the well-bore could move through vertical paths even though the permeability in that direction is relatively low. As a consequence, flow through the bulk of the reservoir rock must be a meandering flow such as would be expected in a radial system. Actually, the potential field and the corresponding lines of flow constitute a complex of meandering paths defined by the "composite" permeability arising from the existing values of the horizontal and vertical components from point to point. The influence of vertical permeability would be to remove the horizontal permeability as the sole criterion of flow at the face of the sand and, for that reason, one would not expect flow at the sand face to be correlative with the horizontal permeability. One of the interesting investigations that might be carried out, using a proper analog, would be to study the composite permeability of a network of conductors arranged so as to represent various combinations of horizontal and vertical permeability components. Such a study, even though carried on under idealized conditions, would serve to interpret the significance of the permeabilities measured on cores in the horizontal direction.

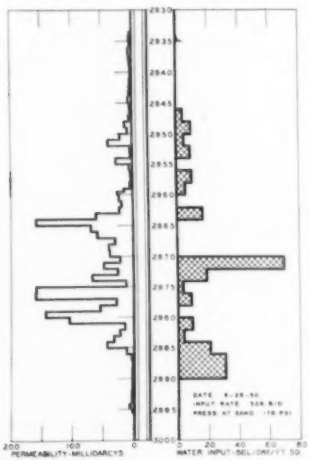

FIG. 6 — PERMEABILITY AND WATER INJECTIVITY LOGS, NBU 127-W-5.

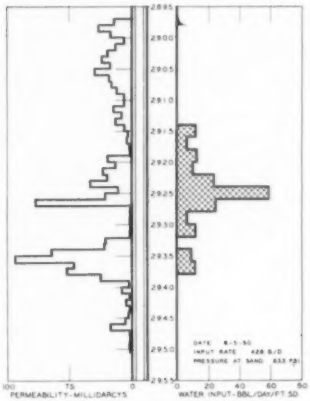

FIG. 7 — PERMEABILITY AND WATER INJECTIVITY LOGS, NBU 127-W-6.

CONCLUSIONS APPLYING TO PRODUCTION PRACTICE

The principle conclusion that comes from the studies herein reported is that most of the practices employing the principle of "selective" control of the flow of fluids at the face of the sand in a well need to be re-examined. It appears doubtful that the operations tailored after the horizontal permeability profile have a sound basis. The horizontal permeability of cores does not measure relatively the flow at the sand face of a productive section. In a similar fashion the concept of "by-passing" based upon observed variations in horizontal permeability needs to be re-examined, particularly in connection with pressure maintenance operations. Eliminating obviously "thief" horizons lying within or immediately adjacent to a common source of supply, and eliminat-

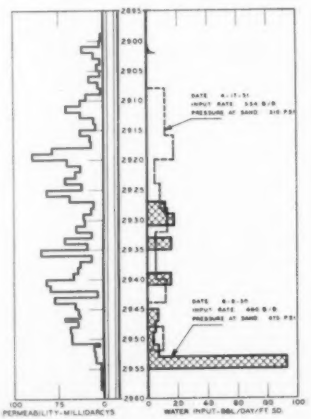

FIG. 8 — PERMEABILITY AND WATER INJECTIVITY LOGS, NBU 127-W-7.

ing recognizable instances of earth cleavage, the conclusions of this paper would indicate that the measured permeability of cores is not a basis for predicting that fluid will pass through only a part of the permeable productive section. In fact, experience in waterflooding operations indicates that the "fill-up," which is the volume of water that needs to be injected before first response is had from offset producing wells, is more often than not quite close to the computed fill-up. This fact indicates that in spite of variation in horizontal permeability, water permeates to and fills the entire body of sand. "Bypassing," in the sense the phrase is usually used, is absent. This confirms the conclusions reached by profile measurements on wells.

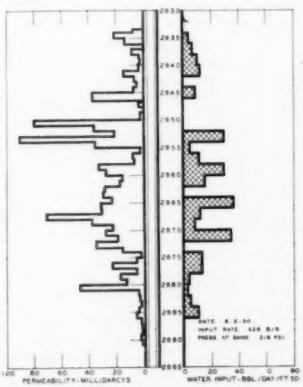

FIG. 9 — PERMEABILITY AND WATER INJECTIVITY LOGS, NBU 127-W-8.

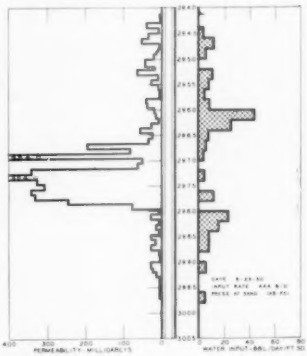

FIG. 10 — PERMEABILITY AND WATER INJECTIVITY LOGS, NBU 127-W-9.

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DISCUSSION

By E. T. Heck, Minard Run Oil Co., Bradford, Pa., Member AIME

Kaveler and Hunter should be complimented on calling attention to the fact that some have erred in over emphasizing the supposed uniformity of actual conditions in oil reservoirs. Their introduction is well worded and appropriate. It appears, however, that these gentlemen have made an even more serious error and assumed that the nine wells they describe are typical of all intake wells, not only in the Burbank sandstone, but everywhere. This writer is familiar with several thousand intake wells and knows of none that take comparable volumes of water at comparable sand face pressures. This fact alone would seem to refute Kaveler and Hunter's basic assumption.

The paper states "the permeability profile logs of wells in any pool are not correlative, even between wells as close as 660 ft and 330 ft apart." In the Bradford-Allegheny fields (well over 100,000 acres of net productive territory) there are literally thousands of cores and electric logs that testify to the existence of a reasonable degree of correlation. Hundreds of acres have been cored and/or electric logged on a density of one well per acre. While remarkable variations in detail are known, overall correlation of the permeability profiles does exist over distances much greater than the figures quoted above. Of course, it is necessary that the profiles be properly matched.*

Very little information is given in the paper on the procedures followed in well completions. Eight of the nine wells were cored with a diamond bit using a "low-water-loss water-base mud." The fact that Fig. 1 shows the core to be flushed (more or less in proportion to the permeability profile as shown by core analysis) indicates that the pressure in the mud column was greater than the reservoir pressure. This fact raises the question of how the sand face was cleaned and prepared for the intake of water. The more permeable layers were probably pretty well plugged during the coring process and unless some positive, effective, action was taken to clean the sand face, all of the observations reported may be readily explained on this basis alone.

The following statement appears to be entirely too sweeping. "Filtered water, treated to prevent growth of bacteria and algae, is injected into these wells and, for that reason, plugging action arising from suspended solids could not account for any of the intake characteristics here reported." This discusser has investigated a number of intake systems and has first-hand knowledge of many others. In no case was the intake system sterile. In the absence of specific tests, it is safe to assume that organic growths are present in the wells in question. Such growths are not so apt to plug cracks as they are the small pores of the sand.

The presence of fractured zones is mentioned in several places in the paper. In fact, it is stated that a large part of the water is entering the fracture system instead of the sand proper. If these fractures cross the bedding planes, there is no reason to expect the intake to be distributed according to the permeabilities shown by the core analyses. On the other hand, if the fracture system does not cross the bedding planes of a major part of the reservoir, there should still be a reflection of the permeabiilty profile, *provid-*

*This fact is very important. The top or bottom of the sand is rarely the correct correlating base. The usual core description can rarely be used and the standard multiple point electric log is little better. Proper correlations require detail inspection of the cores or, even better, detailed electric logs such as those given by the Keller system developed at Pennsylvania State College under the sponsorship of the Penn Grade Crude Oil Association — research program in 1948-49. The "Laterolog" and "Guarded Electrode" systems are apparently analogous. Frequently, an electrical marker can be found, just above or below the sand proper, that will greatly aid in making correct correlations.

ing that the measurements of water inflow are sufficiently accurate.

For example — in well NBU 127-W-1, the 40 md sand should take less than 2 bbl per day per foot of sand. The 5 md sand should take less than 0.5 bbl per day per foot of sand. Due to the large amount of water entering the fracture zone, the metering instrument must have an accuracy considerably better than one per cent. This writer knows of no well metering device of such accuracy. Furthermore, it would be impossible to plot values of this magnitude using the scale shown in Fig. 2.

The following statement is found under the section "A General Conclusion." "It may be concluded, therefore, that the core permeability measurements for any well will not serve as a basis for predicting the fluid flow characteristics of any particular interval in a productive section." As pointed out in this discussion, there are good reasons to doubt that this conclusion is valid even for the wells described in the paper. There is a wealth of information, (some of it, undoubtedly, available to Kaveler and Hunter) on other areas that proves the opposite. Numerous cores drilled in old water floods during reworking operations, demonstrate without question that the flood has progressed in direct ratio to the permeability of the various sections of the sand.

In the section "Conclusions Applying to Production," the authors not only assume that the area discussed in this paper is identical with all other areas, but they reverse the process and cite "fill-up" behavior in other areas as though it is identical with the area under discussion. This piling of assumption upon assumption is never wise and in this case should have been unnecessary. Production data for the surrounding oil wells should have been included in the paper. It would then have been possible for the reader to judge whether or not this flood was behaving in the expected manner.

In conclusion, it may be stated that Kaveler and Hunter have described a problem area that is not at all typical of the vast majority of presently operating water floods. It is probable that many of the problems have been introduced, or at least aggravated by the methods used in well completion and/or operation. This last statement cannot be confirmed on the basis of the information supplied in paper and additional data, particularly complete rate curves on both intakes and producers, is greatly to be desired.

AUTHORS' REPLY TO MR. HECK

The authors appreciate the discussion offered by Heck. All viewpoints must be weighed in arriving at any conclusion and, in addition, discussion will encourage further investigation of the thesis raised, to the benefit of further development of fact. An effort will be made to reply briefly in respect to the points that Heck appears to raise in his discussion.

1. There are wells that take greater volumes of water at lower sand face pressures than do the wells in the North Burbank Sand, and many will be found in the Burbank Sand Area that have intake capacities such as those at North Burbank.

2. The correlation of permeability referred to in the paper was such correlation as to reflect whether or not stratigraphic intervals of the sand ran continuously in a sheet from well to well over a large portion of the reservoir, whereas Heck deals with the existence of "a reasonable degree of correlation" which is an indefinite reference. Furthermore, we have found no means to use electric logs as a means for anything more than just generalized correlations of sand characteristics.

We have been impressed by the observation of Danielson and Martin in Technical Paper No. 181 of the Mineral Industries Experiment Station, Pennsylvania State College, titled "Selective Plugging in the Bradford Field" wherein it is stated: "Oil reservoirs, including those of the Bradford Field, are made up of many sand strata possessing wide variations in permeability. *These strata are separated by impermeable shales which make them independent conductors of fluids.*" The North Burbank reservoir is definitely one common source of supply and is not separated into multiple common sources of supply by strata of shale, which is a fact that is important to bear in mind if experience in one area of the country is compared to experience in the Burbank Sands.

3. In respect to the method of input well completions: The wells were cored with a diamond bit and were not shot. Caliper surveys in each of the wells under test showed a remarkably uniform well bore. When mud was bailed from the wells after drilling was complete, oil and gas came into the well bore. The wells were swabbed and in some cases were acidized with mud acid and in other cases a mechanical scratcher was used to further clean the sand face.

4. Heck overlooks the statement in the paper that permeability plugs cut in the horizontal direction through the core and then broken into three pieces of equal length showed variation in the horizontal permeability over the short distance of four and one-half in. of the core — variation as much as 300 per cent between adjacent pieces with no regularity in variation in respect to location of the piece of core in the diameter. On the face of it, there is substantial variation in horizontal permeability within the reservoir rock. If it occurs within the core, it must undoubtedly occur throughout the body of the sand. Further, in respect to the plugging of wells by either drilling practice or by plugging material in the injected water, we may say that the intake characteristics or the injectivity of the wells were consistent in a general way with the permeability feet of the section. And further, one might observe that whether partial plugging occurred or other effects referred to by Heck were present, the fact still stands that the relative capacity of any interval to take water was not reflected by the core analyses.

5. The profile log showed excessive intake of water in fractured areas in some instances, and in other instances where fracturing appeared in the core the section of sand showed a lower than normal intake capacity; and in that instance, again, the core analyses could not be relied upon to predict intake capacity of any interval, no matter what circumstances might otherwise prevail.

6. A number of cores have been taken in sands following waterflood operations or in sands that were water-invaded in the area of the Burbank Sands, and the residual oil saturation has been found to bear no relation to the specific permeability of the core, and there is no reason, except in the case of parallel common sources of supply separately subject to the action of a waterflood, that the core taken from the sand after waterflooding should show flood progress in direct ratio to the permeability of the various sections of the sand.

7. The "fill-up" in the North Burbank Field where the profile study was carried on was found to be surprisingly close to calculated fill-up, which is the experience that is generally had after the net productive sand thickness is known in waterflooding operations in the area of the Burbank Sands generally.

8. In respect to Heck's final point, we only inquire of how many instances that a reliable profile of fluid flow at the face of the sand has been found to be correlative with the permeability of the core taken in the well. ★ ★ ★

PREDICTION OF SATURATION PRESSURES FOR CONDENSATE-GAS AND VOLATILE-OIL MIXTURES

E. I. ORGANICK AND B. H. GOLDING, UNITED GAS CORP., SHREVEPORT, LA., JUNIOR MEMBERS AIME

ABSTRACT

A simple correlation is presented for the prediction of saturation pressures in condensate-gas and volatile-oil mixtures. Saturation pressure is related directly to the composition of the mixture with the aid of two generalized composition characteristics, $\overline{B}$, the molal average boiling point, and W_m, the modified weight average equivalent molecular weight. The need for hydrocarbon equilibrium constants is entirely eliminated. Only the values of the two composition parameters need be obtained, and these are calculated in a simple and reproducible manner from the stream analysis of the mixture and the ASTM distillation for the heavy ends.

The correlation is given in the form of a set of 14 working charts in which saturation pressures, either retrograde dew points or bubble points, are plotted *vs* temperature, forming partial phase envelopes for mixtures having discrete values of the composition parameters, $\overline{B}$ and W_m. A locus of critical states on each chart intersects the partial phase envelopes, distinguishing retrograde dew point pressures from bubble pressures.

A comparison between experimental and predicted saturation pressures reveals that: the probable error of the predicted values, when considering the data as a whole (214 experimental points), is five per cent; for high gas/oil ratio condensate fluids (approximately 40,000 or more cu ft/bbl) the probable error is about 8 per cent. In either case, however, the probable error is comparable with the overall uncertainty of the data from which the correlation is derived.

INTRODUCTION

There is a present need for a simplified, yet reasonably accurate method for predicting upper phase boundaries of reservoir fluids. In the case of high gas/oil ratio fluids, namely the so-called highly volatile oils and the condensate gases, no simple method, accurate within 5 to 10 per cent, is now available by which bubble point and retrograde dew point pressures may be predicted.

In order to calculate the upper phase boundary of a volatile reservoir fluid, using correlations now available, it is necessary to find and employ the proper *K*-values (equilibrium volatility ratios of the hydrocarbons in that fluid). This process of finding the proper *K*-values usually involves a double trial and error computation. Since the *K*-values are in themselves dependent upon the composition of the fluid, their use in the calculation of a saturation pressure actually represents an unnecessary complication.

The correlation described in this paper relates saturation pressure directly to the stream composition, entirely eliminating the need for *K*-values. The only data required to calculate the stream composition are obtained from the customary low temperature fractional analyses of separator gas and liquid, and from the ASTM distillation of the C_7+ fraction of the separator liquid. A considerable simplification in the procedure for predicting saturation pressures is thereby effected without significant loss in accuracy.

BASIS FOR A CORRELATION

Empirical relationships between the saturation pressure and the composition of the fluid in question have already been partially explored by one of the authors.[6] In particular, a relationship between the critical pressure for a hydrocarbon mixture and its composition was developed. The critical pressure is in reality a saturation pressure, as it represents a limiting case either of a dew point or of a bubble point pressure for any given mixture.

It was found that the critical pressure may be correlated as a function of two generalized composition characteristics or variables. One characteristic expressed a molal average property, the other a weight average property of the mixture. Specifically, the molal average boiling point (MABP, or $\overline{B}$ as it

[6]References given at end of paper.

Manuscript received in the Petroleum Branch office Aug. 17, 1951. Paper presented at the Petroleum Branch Fall Meetings in Oklahoma City, Okla., Oct. 3-5, 1951, and in Los Angeles, Calif., Oct. 25-26, 1951.

will be called in this paper) and the weight average equivalent molecular weight $\overline{W}$, defined below, were used to obtain critical pressure directly from a convenient, empirically derived working chart. As will be shown, the values of the parameters $\overline{B}$ and $\overline{W}$ may be readily computed from the analysis of the mixture. Deviations between observed critical pressures and values predicted from this chart averaged about five per cent, or roughly, a deviation comparable to the uncertainty of the experimental values themselves.

Since critical pressures can be correlated with composition in such a simple manner, it is logical to expect that other saturation pressures along the upper phase boundary may be correlated using similar techniques. This expectation led to the correlation developed and presented below.

TREATMENT OF EXPERIMENTAL DATA

All available experimental dew point and bubble point data for complex hydrocarbon mixtures were collected, and each mixture was analyzed for the purpose of calculating values of $\overline{B}$ and $\overline{W}_m$, the proposed correlating parameters. The definition of these parameters and an outline of the actual techniques used to calculate their numerical values follow.

The molal average boiling point, $\overline{B}$, is defined as the sum of the products of the mol fractions and the boiling points of the individual components,

$$\overline{B} = \Sigma_i \text{ (mol fraction)}_i \cdot \text{(boiling point)}_i$$

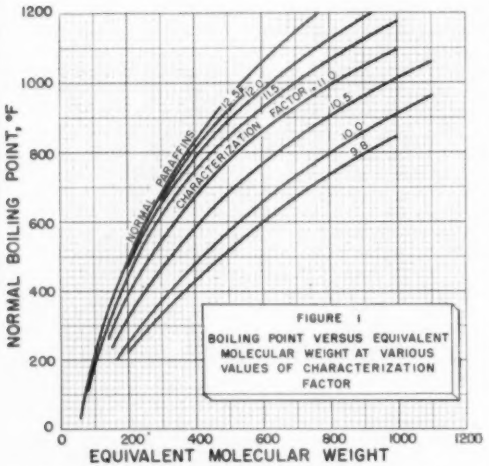

TABLE OF EQUIVALENT MOLECULAR WEIGHTS FOR NATURAL GAS CONSTITUENTS:

Methane	16.0	n-Pentane	72.2
Ethane	30.1	Hexanes	85.0
Propane	44.1	Ethylene	26.2
iso-Butane	54.5	Nitrogen	28.0
n-Butane	58.1	Carbon Dioxide	44.0
iso-Pentane	69.0		

FIG. 1

In this paper $\overline{B}$ is always computed in degrees Rankine.

The modified weight average equivalent molecular weight, $\overline{W}_m$, is a somewhat more complex function. It is defined as a practical approximation to $\overline{W}$, the weight average equivalent molecular weight. The latter has been previously defined[6] as the sum of the products of the weight fractions and the equivalent molecular weights of the individual components:

$$\overline{W} = \Sigma_i \text{ (weight fraction)}_i \cdot \text{(equivalent molecular weight)}_i$$

The equivalent molecular weight is an empirically derived function designed to account for differences in chemical structure of the various hydrocarbon components in a mixture.[6] For a n-paraffin the equivalent molecular weight is the actual molecular weight. For iso-paraffins and for olefin compounds, however, the equivalent molecular weight is defined as the molecular weight that a n-paraffin would have if it boiled at the same temperature as the iso-paraffin or olefin in question. For other hydrocarbons, such as the naphthenic and aromatic types, the equivalent molecular weight is defined in Fig. 1 as a function of the normal-boiling point and also of the Watson or U.O.P. characterization factor.[11]

Unfortunately, the experimental information normally available on naturally occurring mixtures is not sufficient to permit an accurate calculation of $\overline{W}$ for these mixtures. The usual type of analysis available on complex hydrocarbon mixtures, particularly on volatile crude oils and on gas-condensate mixtures, is a low temperature fractionation analysis through pentanes or hexanes combined with an ASTM distillation of the heavy ends. The ASTM distillation is far from being an accurate fractionation and is frequently incomplete because the cracking temperature is reached before the end of the distillation. The heavier the stock, the less complete is the distillation information.

The estimation of the weight average equivalent molecular weight for the C_7+ fraction of these naturally occurring mixtures is thus subject to considerable uncertainty. Furthermore, the calculated numerical values of the weight average equivalent molecular weight for naturally occurring mixtures are generally quite dependent on the value of the weight average equivalent molecular weight assigned to the C_7+ fraction.

For this reason an arbitrary but systematic and reproducible technique has been adopted for estimating the weight average equivalent molecular weight of the C_7+ fraction. The experimental information required consists of an ASTM distillation of the C_7+ and, when feasible, specific gravities of the individual cuts. $\overline{W}_m$ of a mixture or of a portion of a mixture (such as the heavy ends) is defined in this paper as that weight average equivalent molecular weight which is obtained when the weight average equivalent molecular weight of the C_7+ fraction is estimated by the following technique:

Calculation of W_m for the Heavy Ends

1. The ASTM distillation, when incomplete because of cracking, is extrapolated in the following manner. The ASTM boiling points of the C_7+ fraction are plotted on a graph whose coordinates are log boiling point (in degrees absolute) and cumulative weight per cent of the entire mixture from which the C_7+ material is derived. A best straight line is drawn through the plotted points on this graph and extended to the intersection of the line representing 100 cumulative per cent. Boiling point for any portion of the "residue" may then be read directly from the extrapolated portion of this straight line.
2. The heavy ends are broken up into an arbitrary number of cuts each of known average ASTM boiling point and of known or estimated characterization factor.

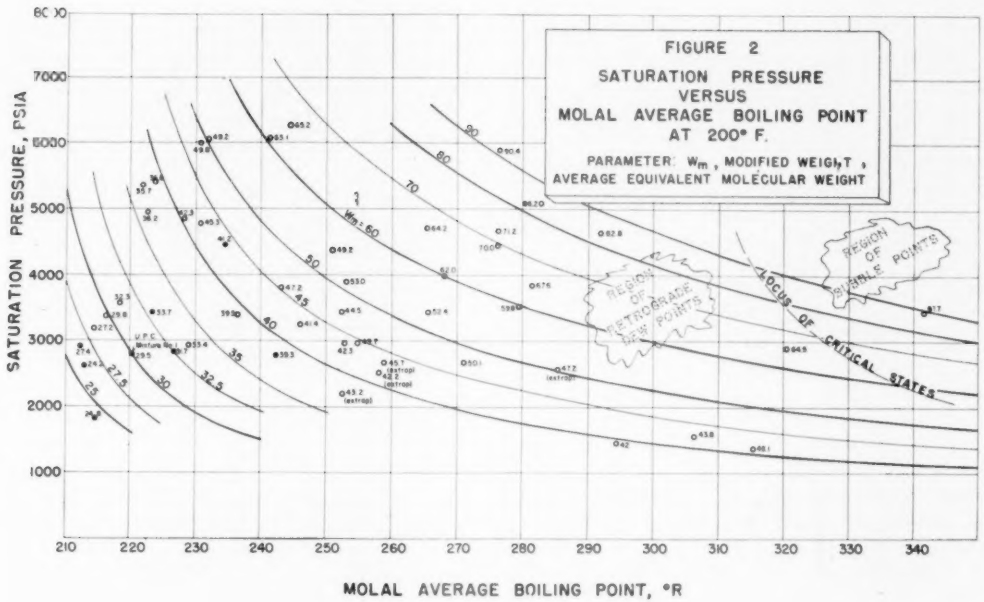

FIG. 2

3. The equivalent molecular weight for each cut of the C_7+ fraction is defined in terms of the ASTM boiling point (rather than true boiling point) and characterization factor of that cut. Fig. 1 is used to obtain the equivalent molecular weights of the cuts.
4. The terms [(weight fraction)$_i$ · (equivalent molecular weight)$_i$] for each cut are summed to obtain the value of W_m.

An illustrative problem, given in a later section, describes in detail the calculations for W_m. Short-cut procedures for computing W_m and $\overline{B}$ for C_7+ fractions are also described.

DISTINCTION BETWEEN SIMPLE AND COMPLEX MIXTURES

The value of W_m of a naturally occurring hydrocarbon mixture calculated by the above procedure is usually less than the value of W for the same mixture. This means that pure components and simple mixtures of pure components (*e.g.*, binary and ternary mixtures) cannot always be treated satisfactorily by the correlation presented in this paper. The value of W for a mixture of methane and normal decane, for example, cannot be compared with the value of W_m for a mixture of methane and a distillate material whose average volatility characteristic is the same as that of normal decane. Since no empirical relationship has been worked out between W and W_m, available data on binary and ternary mixtures of pure components were not included in the preparation of the empirical correlation described below. If this correlation is used to predict the saturation pressure of a simple mixture of pure components, the predicted saturation pressure will generally be somewhat high. It may, however, be possible to develop a similar correlation in terms of W (rather than W_m) and B for direct prediction of the saturation pressures of these simple mixtures of pure components.

THE CORRELATION

Saturation pressures at any given temperature may be correlated as a function of the composition parameters, B and W_m. A plot of the data at 200°F is shown in Fig. 2. This graph shows the first step in the preparation of the final working charts and illustrates several important aspects and limitations of this correlation.

Typical Isothermal Plot of the Data

The saturation pressure for each mixture is plotted *vs* the molal average boiling point, with the value of W_m corresponding to that mixture indicated numerically beside the plotted point. It is apparent that a family of curves representing contant values of W_m may be faired through the points in such a way that each experimental point lies close to the curve corresponding to the W_m value of that point. If the curves define "predicted" values of saturation pressure, the average deviation between predicted and observed pressure for all points in Fig. 2 is about 6 per cent; the maximum deviation is roughly 15 per cent.

Distinction Between Dew Points and Bubble Points

The saturation pressures defined in Fig. 2 may be either retrograde dew points or bubble points. For any given temperature the more volatile the mixture, *i.e.*, the lower the $\overline{B}$ and W_m, the more likely will it exhibit retrograde dew point behavior rather than bubble point behavior. Conversely, heavier mixtures (higher boiling point and higher molecular weight) will more likely exhibit bubble point behavior for any specified temperature. Some mixtures will be at their critical temperatures; consequently, the saturation pressures exhibited for these mixtures will be neither dew points nor bubble points, but critical pressures. These mixtures are defined at each temperature by a locus of critical states as shown in Fig. 2. The region to the left of the critical locus,

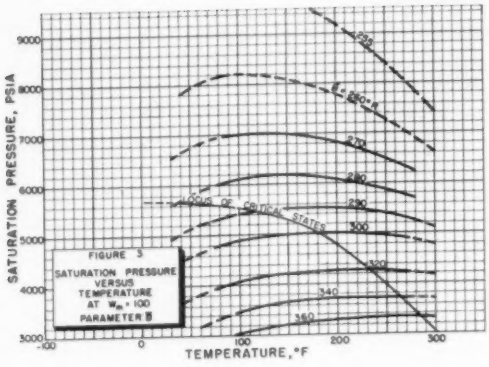

FIG. 3

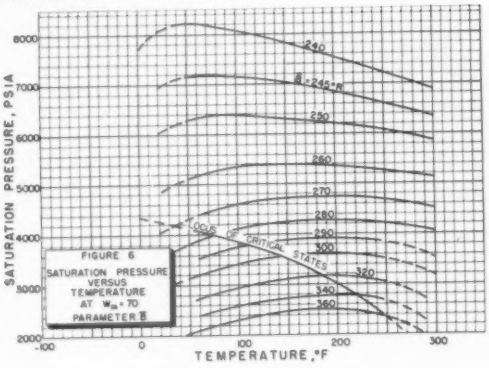

FIG. 6

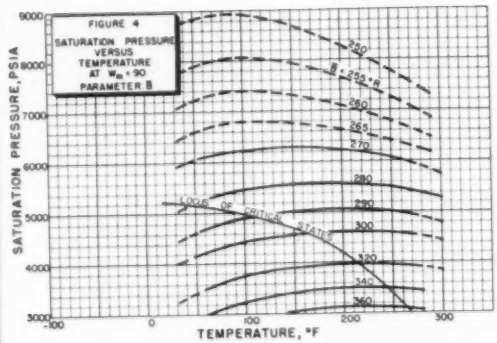

FIG. 4

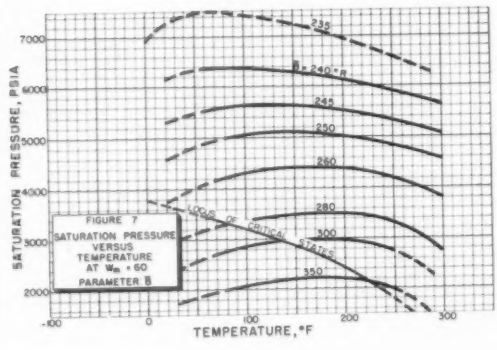

FIG. 7

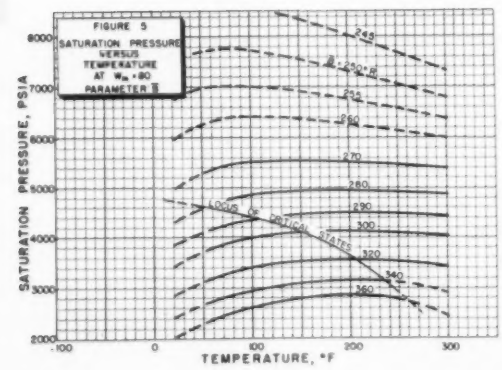

FIG. 5

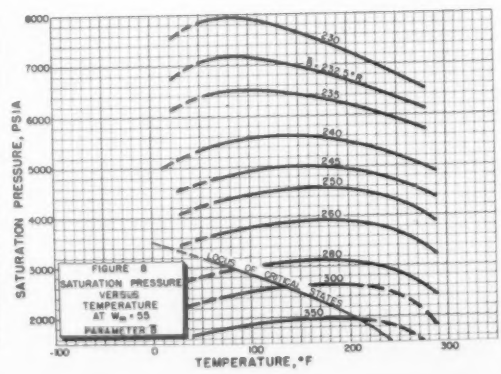

FIG. 8

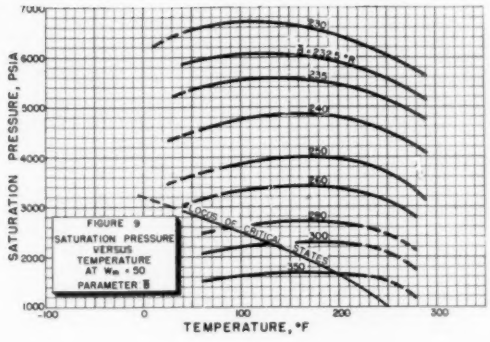

FIG. 9

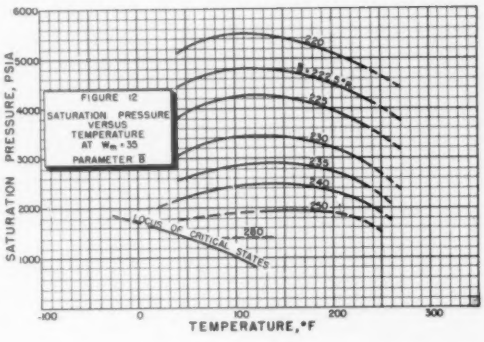

FIG. 12

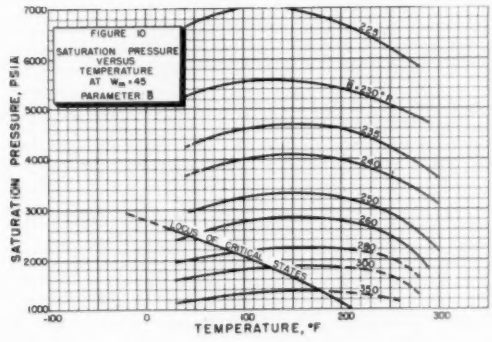

FIG. 10

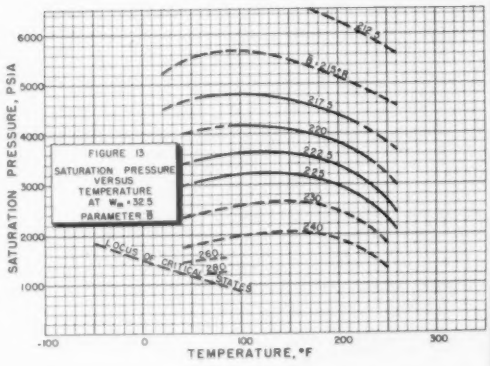

FIG. 13

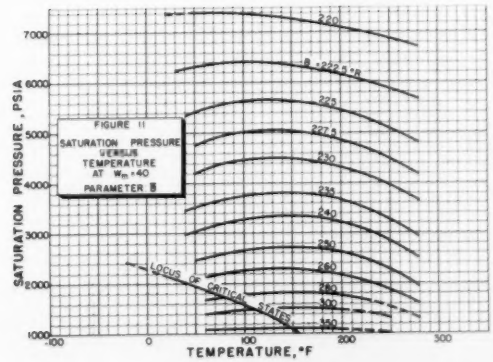

FIG. 11

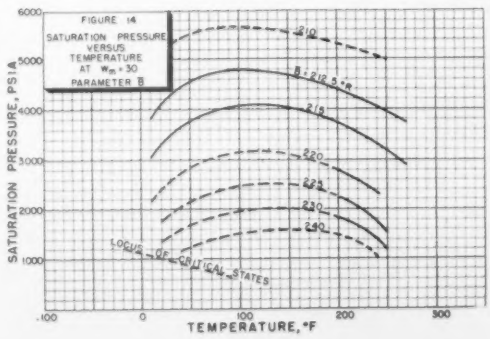

FIG. 14

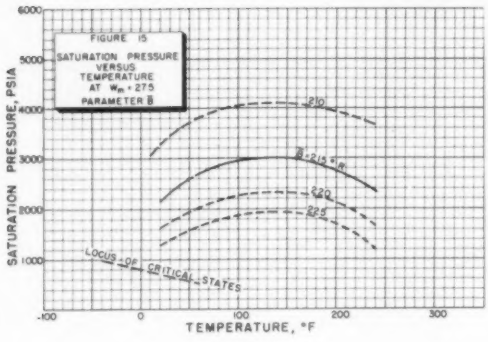

FIG. 15

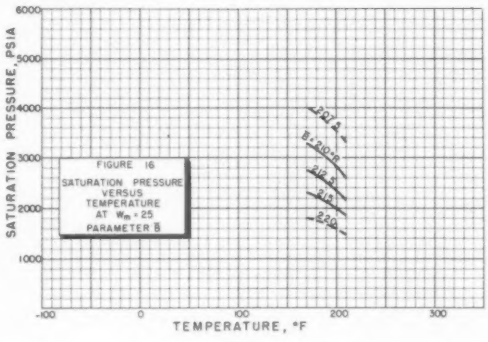

FIG. 16

therefore, denotes retrograde dew point saturation pressures, while the region to the right of this curve represents bubble point saturation pressures. It should be noted also that there is no discontinuity in the transition from mixtures which behave as bubble point liquids to mixtures which behave as condensate gases. In Fig. 2, plotted experimental points are divided into two categories. Open circles refer to data published in the literature and summarized in Tables II through VII. Solid circles refer to unpublished data from files of the United Gas Corp. on Union Producing Co. wells, Table VIII. The latter data represent gas depletion runs on high gas/oil ratio condensate fluids which were observed in an equilibrium windowed cell.

Final Set of Working Charts

The isothermal plots of saturation pressure *vs* molal average boiling point, such as Fig. 2, were cross-plotted and smoothed several ways, once with respect to W_m and once with respect to temperature, yielding as the result a set of 14 working charts, Figs. 3 through 16. Each chart contains a family of partial phase envelopes, or upper phase boundaries, plotted on pressure *vs* temperature coordinates. Each curve in the family represents a hydrocarbon mixture having a different value of $\bar{B}$. Values of W_m are held constant for any one chart. Loci of critical states which intersect the partial phase envelopes separate regions of bubble point and of retrograde dew point behavior on each chart. The determination of the critical states for these complex mixtures is described in another paper.[5] The ranges of $\bar{B}$ and W_m covered in these charts are 210° to 380°R, and 27.5 to 100 respectively. These ranges cover nearly all condensate and highly volatile oil mixtures. The dashed portions of the curves on these plots represent smoothed extrapolations of the correlation into regions in which experimental data are lacking.

Agreement Between the Correlation and Experimental Data

In order to evaluate the accuracy of the recommended working charts, a comparison was made between predicted and observed saturation pressures for all experimental mixtures

Table I — Deviation of Predicted Saturation Pressures from Experimental Values

Part One: Distribution of Deviations According to Source of Data

Source of Data Author Reference	Distribution of Expt'l Points Among Various Per Cent Deviations									Total Number of Expt'l Points	Arithmetic Mean Deviation %	Standard Deviation %
	−25% to −20%	−20% to −15%	−15% to −10%	−10% to −5%	−5% to −0%	0% to 5%	5% to 10%	10% to 15%	15% to 20%			
Eilerts and Smith[2]	0	0	0	0	3	11	10	0	0	24	+ 4	3.1
Hanson and Brown[3]	0	0	0	1	2	3	1	3	0	10	+ 3.6	7.5
Kurata and Katz[4]	0	0	6	12	14	17	8	1	0	58	− 1.3	6.2
Olds, Sage and Lacey[7]	1	0	1	1	6	6	0	0	0	15	− 3.6	6.3
Reamer and Sage[8]	0	1	5	7	7	15	7	9	0	51	+ 1.3	8.4
Sage and Olds[10,5]	0	0	6	7	11	7	4	0	0	35	− 3.2	6.3
Union Producing Co.[12]	0	0	3	3	3	6	5	1	0	21	0.0	8.2
Total Points (or frequency)	1	1	21	31	46	65	35	14	0	214	− 0.19	7.0

Part Two: Distribution of Deviations According to Temperature Range

Temperature Range, °F	< 100	100-150	151-200	201-250	> 250	Entire Range
Number of Points	25	71	58	56	4	214
Maximum Deviation						
Positive	+ 13.3%	+ 13.6%	+ 13.4%	+ 15.0%	+ 6.9	+ 15.0%
Negative	− 14.4%	− 15.5%	− 11.7%	− 21.8%	− 10.1	− 21.8
Arithmetic Mean Deviation	− 1.9%	− 0.64%	+ 1.38%	− 0.1%	+ 0.5%	− 0.19%
Standard Deviation	8.0%	6.7%	6.7%	7.5%	.....	7.0%
95% Confidence Limit for the Arithmetic Mean Deviation	± 3.3%	± 1.56%	± 1.76%	± 2.0%	.....	± 0.93%

in the ranges covered by the charts. At the computed values of $\bar{B}$ and W_m for each mixture, values of saturation pressure were read directly from the working charts or interpolated visually without further crossplotting.

A total of 214 experimental points are listed in Tables II through VIII. Each table represents a different collection of data, and lists computed values of $\bar{B}$ and W_m for each mixture, the experimental and predicted saturation pressures at the observed temperature, and the per cent deviation of the predicted saturation pressure from the observed value. These per cent deviations are summarized for statistical analysis in Table I. Deviations in saturation pressure are expressed as per cents of the observed pressures rather than as absolute pressure differences in order to give equal weight to deviations representing equal *percentage* differences regardless of the absolute value of the observed pressures about which the deviations are recorded.

Part One of Table I shows the frequency of deviations listed in Tables II through VIII according to the source of the data and according to the magnitude of the deviations. The frequency of the deviations for all 214 observations is given in the last row. These deviations are seen, for all practical pur-

Table II — Comparison of Predicted and Observed Saturation Pressures. Data of Eilerts and Smith[3]

Weight Per Cent Trap Gas	W_m	$\bar{B}$ °R	Temp. °F	Sat'n Press. psia Obs.	Sat'n Press. psia Pred.	Per Cent Deviation Pred. from Obs.
28.88	87.9	342.0	70	3005	3050	+ 1.5
			100	3178	3200	+ 0.7
			160	3389	3350	− 1.2
			228	3411	3390	− 0.6
			250	3370	3390	+ 0.6
29.16	87.7	341.5	228	3430	3390	− 1.2
50.01	67.6	281.5	70	3620	3780	+ 4.4
			100	3775	3900	+ 3.3
			160	3870	4100	+ 5.9
			228	3750	4040	+ 7.7
			250	3685	4030	+ 9.4
			280	3575	3820	+ 6.9
66.41	53.0	252.4	70	3690	3810	+ 3.3
			100	3852	3950	+ 2.5
			160	3929	4100	+ 4.4
			228	3775	3980	+ 5.4
			250	3665	3840	+ 4.8
			280	3485	3540	+ 1.6
73.59	47.2	243.1	70	3720	3920	+ 5.4
			100	3850	4080	+ 5.6
			160	3880	4200	+ 7.6
			228	3678	3950	+ 7.4
			250	3555	3800	+ 6.9
			280	3330	3460	+ 3.9

Table III — Comparison of Predicted and Observed Saturation Pressures, Data of Hanson and Brown[7] Natural Gas Type Mixtures

Mixture	W_m	$\bar{B}$ °R	Temp. °F	Sat'n Press. psia Obs.	Sat'n Press. psia Pred.	Per Cent Deviation Pred. from Obs.
A	44.0	285.5	100	1990	2000	+ 0.5
			160	1990	2030	+ 2.0
B	43.0	281.8	100	1980	1960	− 1.0
			160	1900	2030	+ 7.0
*A_v	34.0	252.7	100	1822	1790	− 1.8
	30.5	244.6	100	1639	1490	− 9.0
B_v	32.2	243.2	100	1736	1770	+ 2.0
A_l	52.8	324.7	100	1822	2030	+ 11.4
	57.3	354.3	100	1639	1860	+ 13.6
B_l	53.4	339.7	100	1736	1930	+ 11.1

*A_v Equilibrium vapor phases from mixture A
B_v Equilibrium vapor phases from mixture B
A_l Equilibrium liquid phases from mixture A
B_l Equilibrium liquid phases from mixture B

Table IV — Comparison of Predicted and Observed Saturation Pressures, Data of Kurata and Ka•z[4] Natural Gas - Natural Gasoline Mixtures

Mixture	W_m	$\bar{B}$ °R	Temp. °F	Sat'n Press. psia Obs.	Sat'n Press. psia Pred.	Per Cent Deviation Pred. from Obs.
B-1	39.0	278.6	60*	1803	1600	− 11.3
			80	1830	1640	− 10.9
			100	1840	1680	− 8.6
			120	1823	1730	− 5.1
B-2	42.0	294.5	60*	1776	1600	− 9.8
			100*	1821	1680	− 7.8
			120	1790	1700	− 5.0
			140	1745	1700	− 2.6
			160	1682	1680	− 0.2
B-3	43.8	306.5	60*	1630	1580	− 3.1
			100*	1748	1660	− 4.9
			120*	1754	1700	− 3.0
			140*	1731	1680	− 3.0
			160*	1695	1690	− 0.2
			180	1645	1680	+ 2.1
B-4	45.1	315.6	60*	1635	1540	− 5.8
			100*	1770	1660	− 6.2
			120*	1775	1670	− 5.9
			140*	1739	1680	− 3.4
			160	1670	1680	+ 0.7
			180	1560	1660	+ 6.3
T-1	43.2	252.6	60	2651	2620	− 1.2
			80	2728	2760	+ 1.1
			100	2740	2860	+ 4.2
			120	2721	2875	+ 5.4
			140	2672	2890	+ 8.1
			160	2570	2910	+ 13.2
T-3	45.7	258.9	60*	2650	2720	+ 2.8
			100	2800	2930	+ 4.7
			140	2859	2990	+ 4.7
			160	2850	3000	+ 5.2
			180	2785	3000	+ 7.7
T-4	50.1	271.1	60*	2620	2720	+ 3.9
			80*	2680	2800	+ 4.5
			100	2760	2880	+ 4.2
			120	2790	2910	+ 4.2
			140	2820	2950	+ 4.5
			160	2800	2960	+ 5.8
			180	2730	2960	+ 8.4
			190	2700	2930	+ 8.7
T-5	64.5	320.5	80*	2794	2600	− 6.8
			120*	2928	2740	− 6.5
			160*	2942	2780	− 5.5
			180*	2920	2820	− 3.5
			193	2901	2850	− 1.8
S-2	42.2	258.3	60	2417	2350	− 2.6
			80	2496	2500	+ 0.2
			100	2563	2550	− 0.6
			120	2604	2610	+ 0.2
			140	2613	2620	+ 0.3
			160	2603	2610	+ 0.3
			180	2580	2600	+ 0.8
S-3	47.2	285.5	60	2353	2120	− 9.9
			100	2549	2240	− 12.1
			120	2594	2290	− 11.6
			140	2615	2330	− 10.8
			160	2610	2330	− 9.6
			180	2590	2310	− 10.7

*Indicates bubble point pressures. Remainder of points represent retrograde dew point pressures.

Table V — Comparison of Predicted and Observed Saturation Pressures, Data of Olds, Sage and Lacey[7] Paloma Field, California

Weight Fraction Trap Gas	W_m	$\bar{B}$ °R	Temp. °F	Sat'n Press. psia Obs.	Sat'n Press. psia Pred.	Per Cent Deviation Pred. from Obs.
0.5335	82.8	293.0	100	4490	4440	−1.1
			190	4590	4550	−0.9
			250	4630	4520	−2.4
0.6292	71.2	276.4	100	4560	4470	−2.0
			190	4730	4620	−2.1
			250	4780	4540	−5.1
0.8111	49.2	251.1	100	3835	3670	−4.3
			190	4305	3760	−12.8
			250	4440	3470	−21.8
1st mod.	86.2	282.8	100	4967	5070	+2.0
			190	5077	5180	+2.0
			250	5022	5100	+1.5
2nd mod.	90.4	276.5	100	5910	5950	+0.8
			190	5815	5870	+0.8
			250	5644	5750	+1.9

Table VI — Comparison of Predicted and Observed Saturation Pressures, Data of Reamer and Sage[9] Louisiana Fields

Mixture	W_m	$\bar{B}$ °R	Temp. °F	Sat'n Press. psia Obs.	Sat'n Press. psia Pred.	Per Cent Deviation Pred. from Obs.
A-1	45.3	230.8	40	4494	5090	+13.3
			100	4810	5400	+12.3
			160	4858	5420	+11.6
A-2	42.3	228.2	200	4758	5320	+11.8
			40	4630	5090	+9.9
			100	4914	5370	+9.9
			160	4943	5310	+7.4
A-3	36.2	222.7	200	4830	5200	+7.7
			40	4850	5200	+3.1
			100	5115	5450	+6.5
			160	5106	5370	+4.9
C-1	65.3	244.5	200	4943	5180	+4.8
			100	6650	6450	−3.0
			160	6440	6370	−1.1
			220	6145	6160	+0.2
C-2	49.2	232.0	250	5930	5980	+0.8
			100	6400	5900	−7.8
			160	6190	5910	−4.5
			220	5900	5690	−3.6
C-3	36.9	223.6	250	5700	5450	−4.4
			100	5750	5350	−7.0
			160	5550	5050	−9.0
			220	5280	4730	−10.4
D-1	63.1	241.4	250	5090	4450	−12.4
			100	6400	6700	+4.7
			160	6220	6520	+4.8
			220	5940	6350	+6.9
D-2	49.8	230.7	250	5740	6150	+7.2
			100	6380	6450	+1.1
			160	6170	6360	+3.1
			220	5870	6120	+4.3
D-3	35.7	221.8	250	5660	5850	+3.2
			100	5780	5400	−6.6
			160	5580	5330	−4.5
			220	5230	4950	−5.3
E-1	32.2	218.3	250	5010	4700	−6.2
			100	4020	4450	+10.7
			130	3935	4450	+13.2
			160	3825	4300	+12.2
			190	3658	4150	+13.4
E-2	29.8	216.4	220	3345	3850	+15.0
			100	3815	3760	−1.4
			130	3729	3780	+1.3
			160	3605	3650	+1.2
			190	3445	3480	+1.0
E-3	27.3	214.5	220	3145	3200	+1.8
			100	3612	3050	−15.5
			130	3520	3070	−12.7
			160	3405	3100	−8.9
			190	3265	2880	−11.7
			220	2990	2680	−10.4

Table VII — Comparison of Predicted and Observed Saturation Pressures San Joaquin Valley Field, California

Mixture	W_m	$\bar{B}$ °R	Temp. °F	Sat'n Press. psia Obs.	Sat'n Press. psia Pred.	Per Cent Deviation Pred. from Obs.
			Data of Sage and Olds[10]			
A-1	44.5	252.5	40	3095	2650	−14.4
			100	3394	3040	−10.7
			160	3480	3100	−10.9
A-2	41.4	246.0	220	3295	2990	−9.3
			40	3010	2720	−9.6
			100	3245	3120	−3.9
			160	3294	3130	−5.0
B-1	62.0	270.0	220	3073	2940	−4.3
			100	3900	3980	+2.1
			190	3850	4120	+7.0
B-2	39.5	236.5	250	3655	3910	+7.0
			100	3600	3450	−4.2
			160	3288	3450	+4.9
B-3	33.4	229.0	100	3010	3100	+3.0
			160	2960	3160	+6.8
C-1	43.7	253.7	40	2820	2480	−12.0
			100	3080	2880	−6.5
			160	3090	2900	−6.2
C-2	42.3	252.8	220	2795	2760	−1.3
			40	2810	2410	−14.2
			100	3065	2790	−9.0
			160	3075	2850	−7.3
D-1	70.0	276.2	220	2780	2860	+2.9
			100	4060	4340	+6.9
			190	4388	4490	+2.3
D-2	64.2	268.4	250	4420	4410	−0.2
			100	4344	4240	−2.4
			190	4677	4430	−5.3
			250	4705	4200	−10.7
			Data of Olds, Sage and Lacey[8]			
1	59.8	279.5	100	3300	3360	+1.8
			190	3494	3510	+0.5
			250	3385	3320	−1.9
2	52.4	265.6	100	3325	3260	−2.0
			190	3420	3330	−2.6
			250	3220	3140	−2.5

Table VIII — Comparison of Predicted and Observed Saturation Pressures, Data of Union Producing Co.[12] Mid-Continent and Gulf Coast Fields

Mixture	W_m	$\bar{B}$ °R	Temp. °F	Sat'n Press. psia Obs.	Sat'n Press. psia Pred.	Per Cent Deviation Pred. from Obs.
1	29.5	220.1	199	2760	2650	−4.0
2	39.3	242.2	202	2740	2860	+4.4
3	54.0	270.0	230	3200	3240	+1.3
4	31.1	227.8	219	2380	2160	−9.2
5	36.0	233.3	229	3020	2950	−2.3
6	34.6	232.1	233	2500	2610	+4.4
7	33.3	229.3	233	2650	2700	+1.9
8	35.8	232.3	230	2820	2930	+3.9
9	35.8	231.9	233	2740	2970	+8.4
10	36.4	234.6	235	2800	3000	+7.1
11	33.9	229.5	217	3120	3030	−2.9
12	33.5	229.3	213	2620	2980	+13.7
13	31.7	226.6	206	2750	2530	−8.0
14	72.8	268.5	280	5560	5000	−10.1
15	45.2	239.2	240	4560	3880	−14.9
16	33.6	223.3	199	3400	3700	+8.8
17	41.2	233.9	211	4587	3980	−13.2
18	45.3	256.0	238	3050	2880	−5.6
19	27.4	212.3	196	2950	3150	+6.8
20	34.2	231.2	215	2520	2770	+9.9
21	32.2	228.1	215	2375	2390	+0.6

poses, to be normally distributed about 0 per cent deviation. The overall arithmetic mean deviation is in fact –0.19 per cent, or substantially zero, while the standard deviation about this mean is 7.0 per cent.

Part Two of Table I describes the distribution of the same per cent deviation according to temperature range. The number of experimental points falling in each range and the maximum positive and negative deviations found in each range of temperature are given in the first two rows, respectively. No significant trend is noticeable in the value of the arithmetic mean deviations over the five temperature ranges chosen, as may be seen in row three, indicating thereby that the saturation pressure curves are drawn with approximately the same degree of fit to the experimental points in all ranges of temperature. The standard deviation about each of the five mean deviations (row four) are all of the same order of magnitude as that for the entire group. Ninety-five per cent confidence limits for these arithmetic mean deviations are given in the last line.

Probable Accuracy of the Correlation

The probable error for the data taken as a whole is about five per cent, or approximately the same as the overall uncertainty for most of the data from which the correlation is derived. It should be noted, however, that the data for condensate mixtures having high gas/oil ratios (greater than about 40,000 cu ft/bbl) have a somewhat greater uncertainty than five per cent. Examples of these mixtures are found in references 9 and 12. The increased uncertainty for these mixtures is due to at least two factors: (1) The difficulty in measuring accurately the exact ratio of separator gas to separator liquid charged to the experimental cell in the recombination study. (2) The difficulty in measuring accurately the proportionately smaller quantities of condensed liquid obtained in the retrograde region. As more accurate dew point data for these mixtures become available, it may be possible to improve considerably the correlation in this region.

ILLUSTRATIVE PROBLEM

In order to clarify the procedure to be followed when applying the correlation to an actual problem, an illustrative example is given here.

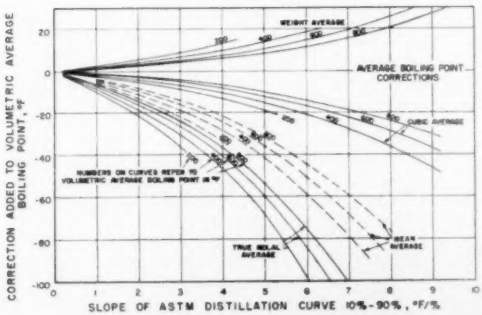
CORRECTION ADDED TO VOLUMETRIC AVERAGE BOILING POINT, °F
SLOPE OF ASTM DISTILLATION CURVE 10%-90%, °F/%
WEIGHT AVERAGE
AVERAGE BOILING POINT CORRECTIONS
CUBIC AVERAGE
MEAN AVERAGE
TRUE BOILING AVERAGE

FIG. 17 — CORRECTION TO VOLUMETRIC AVERAGE BOILING POINTS.

Problem

To predict the dew point pressure at 199°F for a well effluent having the following composition (Mixture No. 1, Table VIII):

Well Stream Composition

Component	Molecular Weight	Separator Gas Wt. Fraction	Separator Liquid Wt. Fraction	Well Stream Weight Fraction	Well Stream Mol Fraction
CO_2	44	.0145		.0134	.0059
N_2	28	.0334		.0316	.0218
C_1	16.04	.7910	.0155	.7313	.8860
C_2	30.07	.0762	.0096	.0713	.0460
C_3	44.09	.0317	.0164	.0306	.0134
i-C_4	58.12	.0137	.0114	.0135	.0045
n-C_4	58.12	.0137	.0217	.0144	.0048
i-C_5	72.15	.0075	.0348	.0097	.0026
n-C_5	72.15	.0068	.0221	.0078	.0021
$C_{6's}$	86.17	.0090	.1078	.0164	.0037
C_7+*	114	.0025		.0018	.0003
C_7+**	139		.7607	.0582	.0081

*Separator Gas
**Separator Liquid

ASTM Distillation of C_7+ from Separator Liquid
Gravity: 56.3° API; 0.7535 g/ml

Distillation	
I.B.P.	216°F
10%	232
20%	245
30%	260
40%	289
50%	313
60%	349
70%	383
80%	416
90%	497
95%	
End Point	

Remarks: 10 – 90 Slope = 3.31
Volumetric Average B. Pt. = 337°F

Solution

Step 1. Calculation of Molal and Weight Average Properties of the Heavy Ends.

In order to compute $\overline{B}$ and $\overline{W}_m$ for the well stream composition, it is desirable first to determine these properties for the C_7+ fractions in the separator gas and separator liquid streams. The C_7+ fraction from the separator gas may be assumed to have the properties of normal octane: $B = 718$°R and $\overline{W}_m = 114$. Two methods are recommended for computing $\overline{B}$ and $\overline{W}_m$ for the C_7+ in the separator liquid. The first method is a short-cut procedure designed for quick estimates of these properties. For more accurate calculation of $\overline{B}$ and $\overline{W}_m$ the second, somewhat more involved method, is recommended.

The first method, the short-cut procedure, assumes that $\overline{B}$ is approximately equal to the mean average boiling point and that $\overline{W}_m$ for a C_7+ fraction may be obtained directly from the ASTM slope and the average characterization factor.

The mean average boiling point as obtained from Fig. 17[11] is 316°F, or 776°R.

$\overline{W}_m$ is obtained from the ASTM slope and the average characterization factor. The latter may be read from Fig. 18[8] from a knowledge of the density and the cubic average boiling point. Fig. 17 is also used to obtain the cubic average boiling point which is 328°F. From Fig. 18, the average characterization is 12.3. $\overline{W}_m$ may now be read directly from Fig. 19, which is a plot of $\overline{W}_m$ *vs* ASTM slope with lines of constant characterization factor. From this chart, $\overline{W}_m = 142$.

The second method is a more precise calculation because the heavy ends are broken up into a number of arbitrarily

selected cuts. The properties of each cut are ascertained and summed to obtain the property of the entire fraction. Table IX summarizes this calculation. Columns 3 and 4 list the mid-boiling points of 10 selected cuts as read from the ASTM distillation curve plotted in Fig. 20. This curve is obtained from the data given in the statement of the problem. If it is assumed that the characterization factor is identical for all cuts (12.3), Fig. 18 may be used to obtain the densities and weights of each cut listed in columns 5 and 6. For a 100 ml sample, assuming no losses, the total weight of the 10 cuts should be 75.35 g since the density was given as 0.7535 g/ml. The weight of each cut, therefore, may be expressed as a weight fraction of the entire separator liquid (column 7) by multiplying the weight of each cut by the ratio 0.7607/75.35, the ratio of the weight fraction of the C_7+ to the total weight of C_7+. These weight fractions are expressed as cumulative weight fractions of the separator liquid (column 9).

A plot of log absolute mid-boiling point *vs* average cumulative weight per cent is constructed (Fig. 21). A best straight line through all points in Fig. 21 is extrapolated to 100 cumulative per cent and the average boiling point of the residue (cut No. 10) is obtained from the extrapolated portion of the line. This value, 940°R, or 480°F, is used to determine the density and thus the weight of the cut (7.97 g).

Two parenthetical remarks are in order here: (1) The fact that the total weight of the C_7+ fraction (75.20 g), as obtained from column 6, checks fairly closely with the actual weight (75.35 g) serves as a check on the original assumption that the characterization factors for the various cuts were substantially the same; (2) the technique used for extrapolating the distillation curve to 100 per cent is probably more elaborate than is necessary in this instance. Any reasonable extrapolation from 90 per cent to 100 per cent, such as the one shown in Fig. 20, would be satisfactory. Extrapolating on log absolute boiling point *vs* cumulative weight per cent coordinates is recommended primarily when treating higher boiling mixtures,

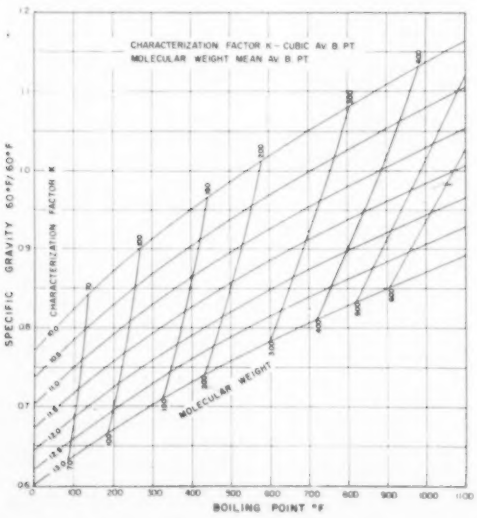

FIG. 18 — RELATIONSHIPS BETWEEN MOLECULAR WEIGHT, CHARACTERIZATION FACTOR, DENSITY, AND BOILING POINTS.

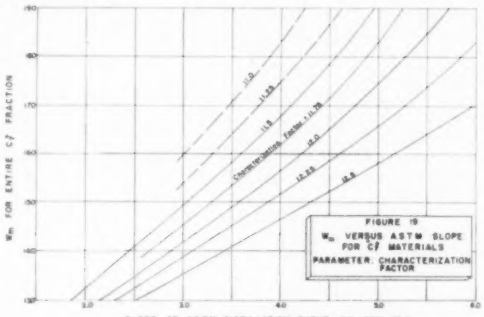
W_m FOR ENTIRE C_7 FRACTION
CHARACTERIZATION FACTOR
FIGURE 19
W_m VERSUS ASTM SLOPE FOR C_7 MATERIALS
PARAMETER: CHARACTERIZATION FACTOR
SLOPE OF ASTM DISTILLATION CURVE 10%-90%, °F/%

FIG. 19

where the extrapolation is more extended. It is used here principally for illustrative purposes.

The equivalent molecular weight fraction of each cut (column 10) is a function of the average boiling point and the characterization factor and may be read from Fig. 1. The weight average equivalent molecular weight for the entire C_7+ fraction is then computed to be 142.8, the summation in column 11 divided by the total weight of sample, found in column 6. The molal average boiling point for the C_7+ fraction is shown as the summation of column 14 divided by the summation of column 13, the total mols of sample, and is 778°R. The mols are computed in column 13 by using the actual molecular weights as read from Fig. 18 from a knowledge of the boiling point and characterization factor or density for each individual cut.

The close agreement between the values of $\overline{B}$ and W_m for the C_7+ fraction as computed by the long method and by the short-cut procedure indicates that the short-cut procedure would have been entirely adequate in this case:

	$\overline{B}(C_7+)$	$W_m(C_7+)$
Accurate method	778°R	142.8
Short-cut method	776°R	142

Step 2. Calculation of $\overline{B}$ and W_m for the Well Stream Composition.

Once the properties of the C_7+ materials have been determined, it is possible to compute the values of B and W_m for the well stream composition, as shown in Table X.

Columns 1 and 4 are merely a restatement of the original well stream composition. Columns 2 and 5 represent boiling points and equivalent molecular weights of the hydrocarbons including the lumped values for the C_7+ fraction as computed in Table IX. In computing $\overline{B}$, the molecular weight of the C_7+ fraction which is used is that obtained from Table IX (or that obtained from Fig. 18 if the short-cut method were used). B for the well stream is the summation in column 3, or 219.8°R. W_m is the summation in column 6, or 29.4.

Step 3. Reading the Saturation Pressure from the Working Charts.

The values of $\overline{B}$ and W_m just computed define somewhere in Figs. 3-16 a unique saturation pressure at any given temperature. In the present case the saturation pressure is interpolated between Figs. 15 and 14. At a temperature of 199°F and at $\overline{B}$ equal 219.8°R, the saturation pressure read from Fig. 15 ($W_m = 27.5$) is 2,150 psia, while from Fig. 14 ($W_m = 30$) it is 2,860 psia. The interpolated value for $W_m = 29.4$, therefore, is about 2,690 psia. This saturation pressure is clearly a retrograde dew point pressure since it lies to the right of the critical loci indicated in Figs. 15 and 14.

Table IX — Calculation of Molal and Weight Average Properties of the Heptanes and Heavier Fraction of the Separator Liquid

Cut. No.	ml	Mid-boiling Pt., °F	Mid-boiling Pt., °R	Density, g/ml	Wt, g	Wt. Fraction of Separator Liquid, g × .7607 / 75.35	Cumulative Wt. Fraction of Separator Liquid	Avg. Cumulative Wt. Fraction of Separator Liquid	Equivalent Molecular Wt.	g × Equivalent Molecular Wt.	Actual Molecular Wt.	mols = g / Mol. Wt.	mols × Boiling Pt., °R
1	2	3	4	5	6	7	8	9	10	11	12	13	14
							.2393						
1	10	223	683	.716	7.16	.0723	.3116	.2755	103	737	106	.0675	46.1
2	10	239	699	.721	7.21	.0728	.3844	.3480	109	786	110	.0655	45.8
3	10	255	715	.727	7.27	.0734	.4578	.4211	112	814	115	.0632	45.2
4	10	275	735	.734	7.34	.0741	.5319	.4949	119	873	122	.0602	44.2
5	10	300	760	.743	7.43	.0750	.6069	.5694	127	944	131	.0567	43.1
6	10	330	790	.752	7.52	.0759	.6828	.6449	137	1030	141	.0533	42.1
7	10	366	836	.764	7.64	.0771	.7599	.7214	150	1146	155	.0493	41.2
8	10	406	866	.776	7.76	.0783	.8382	.7991	168	1304	172	.0451	39.1
9	10	458	918	.790	7.90	.0798	.9180	.8781	191	1509	195	.0405	37.2
10 (res)	10	(480)*	(940)*	(.797)	(7.97)	.0805	.9985	.9583	200	1594	207	.0385	36.2
	Total				75.20					10737		.5398	420.2

$$\bar{W}_m = \frac{10737}{75.20} = 142.8$$

$$\text{Mol Wt} = \frac{75.20}{.5398} = 139.3 \qquad \bar{B} = \frac{420.2}{.5398} = 778°\text{R}$$

*Extrapolated values read from Fig. 21.

It may be noted that the predicted dew point pressure of 2,690 psia compares well with the experimental value, which is 2,760 psia.

THEORETICAL CONSIDERATIONS

Speculation as to the reason for the effectiveness of the two composition parameters, $\bar{B}$ and $\bar{W}_m$, in correlating saturation pressures is worthwhile in that it may point the way for future investigations. It is well known that only two composition parameters are necessary to define adequately the composition of a ternary mixture. From this it follows that by employing a two-parameter correlation for complex mixtures, each mixture is treated as if it were a "restricted" multicomponent mixture having many of the characteristics of a ternary mixture. It cannot, of course, be concluded, prior to an actual investigation, that the mere restriction of the degrees of freedom of the composition to two for all mixtures permits a correlation with sufficient accuracy. Nor is it likely that any two composition parameters when used in combination will be as effective as any other two, even if it turns out that only two properly chosen parameters are sufficient. The discussion which follows is, therefore, an attempt to explain, after-the-fact, the effectiveness of the particular parameters, $\bar{B}$ and $\bar{W}_m$.

To begin with certain generalizations concerning the composition of naturally occurring mixtures are in order.

Distribution Among Components of a Mixture

Any naturally occurring mixture may be viewed statistically with regard to the number of molecules of each component contained in that mixture. The incidence, or frequency of any one component is, in addition to being a function of the temperature and pressure, directly related to the relative volatility of that component and, consequently, also related to any other property (such as the molecular weight) of which

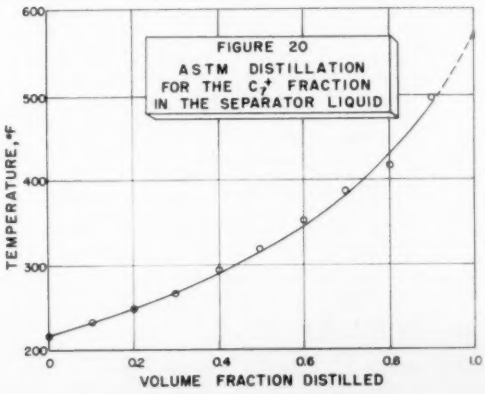

FIG. 20

Table X — Calculation of $\bar{B}$ and $\bar{W}_m$ for the Well Stream Analysis

Component	1 Mol Fraction	2 Boiling Point, °R	3 Mol Frac. x Boiling Point, °R	4 Weight Fraction	5 Equiv. Mol. Wt.	6 Wt. Frac. x Equiv. Mol. Wt.
CO_2	.0059	350	2.06	.0134	44	.59
N_2	.0218	139	3.03	.0316	28	.88
C_1	.8860	201	178.09	.7313	16.04	11.73
C_2	.0460	332	15.27	.0713	30.1	2.15
C_3	.0134	416	5.57	.0306	44.1	1.35
iC_4	.0045	471	2.12	.0135	54.5	.74
nC_4	.0048	491	2.36	.0144	58.1	.84
iC_5	.0026	542	1.41	.0097	69	.67
nC_5	.0021	557	1.17	.0078	72.2	.56
C_6's	.0037	600	2.22	.0164	85	1.39
C_7+ Sep. gas	.0003	718	.22	.0018	114	.21
C_7+ Sep. liq.	.0081	778°	6.30	.0582	142.8°	8.31

$\bar{B} = 219.8°\text{R}$ $\bar{W}_m = 29.4$

*Computed in Table IX.

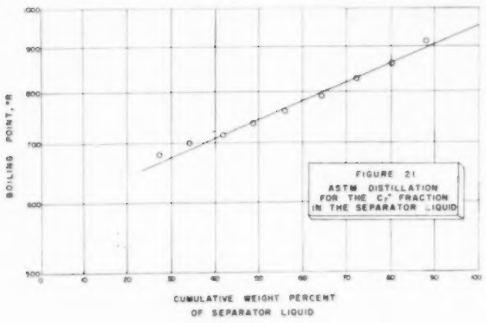
BOILING POINT, °R
CUMULATIVE WEIGHT PERCENT OF SEPARATOR LIQUID
FIGURE 21
ASTM DISTILLATION FOR THE C_7^+ FRACTION IN THE SEPARATOR LIQUID

FIG. 21

the volatility is a function. For example, a typical natural gas existing at its dew point has a distribution of components characterized by the presence of progressively smaller and smaller amounts of the high boiling components which are characteristically non-gaseous at the existing temperature. Similarly, a typical naturally occurring crude oil existing at its bubble point contains progressively smaller and smaller amounts of the low boiling components which are characteristically non-liquid at the existing temperature. To go one step further, a saturated condensate liquid, obtained from a natural gas cap over a crude oil reservoir, has a distribution of components which is characterized by having progressively smaller and smaller quantities of both heavy and light ends (methane excepted) about some central of average boiling component.

Relationship Between the Distribution of Components and Selected Composition Parameters

It may be possible with a set of selected composition parameters, to describe statistically the composition of a mixture in terms of the mean value and in terms of the distribution about the mean value, of any property of the components in that mixture. The boiling point, for example, may be used as the characterizing property to describe the composition of a naturally occurring mixture.

The molal average boiling point may be selected as the parameter which describes the mean boiling point for the mixture. This parameter as defined in Table XI is the first moment of the boiling point. The second moment, defined in Table XI, may also be selected as a composition parameter. This second moment provides information concerning the distribution of components about that component which has a boiling point equal to the mean value.

Higher moments about the mean value provide still more definition of the distribution of components about the mean. In general, each succeeding moment, when used as a composition parameter, adds less information than the preceding one. Consequently, for any particular correlation in which compositions of mixtures are to be described by these parameters, there is always a practical limit to the number of such parameters which may be used effectively. Furthermore, if the composition parameters are used to describe mixtures whose distributions of components about any given mean value are roughly similar, as is the case for naturally occurring mixtures, it is reasonable that relatively few of these parameters are required.

It has been shown mathematically that $\bar{W}_m$ is in fact related to the second moment of the boiling point,[5] so that the parameters $\bar{B}$ and $\bar{W}_m$, when used in combination, describe a complex mixture by referring its composition to a component of mean volatility and to the distribution of the actual components about that component of mean volatility. Since saturation pressure at any given temperature is a function only of the composition, it is possible to account in this way for the effectiveness of these parameters in correlating saturation pressures.

FUTURE INVESTIGATIONS

The foregoing analysis carries with it the implication that the correlating technique described here is a general one and may be used for predicting other physical properties of complex naturally occurring mixtures, such as saturated densities and viscosities of mixtures along the upper phase envelope. Perhaps, in addition to properties in the single phase, the technique may prove useful for predicting two-phase conditions such as the relative quantity of liquid and gas within the phase envelope as a function of pressure and temperature. If this latter proves feasible, it may eventually be possible to construct a nearly complete phase diagram from a set of generalized composition coordinates for the mixture in question. It is hoped that further work along these lines may be reported soon.

CONCLUSIONS

An empirical correlation has been developed for predicting saturation pressures in natural gas-condensate and volatile oil mixtures. Saturation pressure is related directly to the composition of the mixture with the aid of two generalized composition characteristics: B, the molal average boiling point, and $\bar{W}_m$, defined as the modified weight average equivalent molecular weight. Each composition parameter may be calculated in a simple and reproducible manner from the stream analysis of the mixture and an ASTM distillation on the C_7+ fraction. It is preferable, although not essential, to know also the specific gravity of several cuts from the ASTM distillation in order to determine more precisely the characterization factor of these cuts.

The correlation is presented in the form of a set of 14 working charts in which saturation pressures (retrograde dew point or bubble points) are plotted *vs* temperature, forming partial phase envelopes for mixtures having discrete values of the composition parameters, $\bar{B}$ and $\bar{W}_m$. The intervals between the plotted values of $\bar{B}$ and $\bar{W}_m$ are sufficiently small to permit visual interpolation.

Table XI — Definition of the Mean Value* and Its Moments

First Moment (= Mean Value)	$= \Sigma_i$ mol fraction$_i \cdot B_i$
Second Moment	$= \Sigma_i$ mol fraction$_i \cdot B_i^2$
Third Moment	$= \Sigma_i$ mol fraction$_i \cdot B_i^3$
nth Moment	$= \Sigma_i$ mol fraction$_i \cdot B_i^{n-1}$

*Arbitrarily selected to be the molal average boiling point in this case.

A comparison between experimental saturation pressures and those predicted from the working charts of this correlation reveals that:

1. The probable error when considering the data as a whole (214 experimental points) is about five per cent, or approximately the same as the overall uncertainty of the data from which the correlation is derived.

2. For high gas/oil ratio condensate fluids, approximately 40,000 or more cu ft/bbl, the probable error is about eight per cent, perhaps because of the greater uncertainty of the available experimental data for mixtures of this type.

Other empirical techniques may exist for predicting saturation pressures of condensate and volatile oil mixtures to the same degree of accuracy. The technique presented in this report, however, eliminates completely the use of the hydrocarbon *K*-values. It is believed, therefore, that an important simplification of the problem has been effected, providing the engineer with a quick yet accurate method for predicting saturation pressures.

ACKNOWLEDGMENT

The authors wish to thank W. M. Dow for his constructive suggestions. The authors also wish to express their appreciation to the United Gas Corp. for permission to prepare and publish this paper.

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DISCUSSION

By C. Kenneth Eilerts, U. S. Bureau of Mines, Bartlesville, Okla., Member AIME

We have used the correlations of Organick and Golding to estimate the dew points at reservoir temperature of two gas-condensate fluids on which measured dew points are available, with results indicating agreement to within 50 psi in one case and less than 500 psi in the other. One of these fluids was well above and the other well below average in liquid/gas ratio, and both fluids have been found difficult to correlate on any basis. The test made of the authors' diagrams for estimating phase-boundary pressure is probably a severe one, and it seems likely that lower differences between measured and computed pressures would be experienced on fluids with liquid/gas ratios in the proximity of 1.0 gal per Mcf of gas.

The authors are to be commended for developing a correlation method that can be applied to multicomponent hydrocarbon mixtures on a statistical basis. Computation of "molal average boiling points," "weight average equivalent molecular weight," and similar functions seems to be a logical step in estimating the properties of a complex hydrocarbon mixture from the properties and concentrations of its components.

We have found, however, that a further step is desirable in predicting some phase boundary properties of gas-condensate fluids, such as the critical temperature and the cricondenbar pressure or maximum pressure for coexistence of gas and liquid phases. The first step may consist of use of functions of the type,

$$T_{cc} = \frac{N_1 B_1 T_{c1} + N_2 B_2 T_{c2} + \ldots}{N_1 B_1 + N_2 B_2 + \ldots} \quad \ldots\ldots (1)$$

where

T_{cc} = a particular property of a mixture that is to be computed.

$T_{c1}, T_{c2} \ldots$ = values of the corresponding property of the respective components in the mixture.

$N_1, N_2 \ldots$ = mole fraction of components 1, 2 . . . in the mixture, and

$B_1, B_2 \ldots$ = a suitable property of components 1, 2 . . . for altering their relative effects in the summation. The value of B may be unity in all terms.

This function, however, does not provide for values of T_{cc} that may be more or less than the value of the corresponding property for any component in the mixture. For example, the cricondenbar pressure and the critical pressure of a gas-condensate fluid can be and usually are greater than the critical pressure of any component in the fluid. We have shown* that the critical temperature of a gas-condensate fluid can be lower than the critical temperature of either the separator gas or liquid of the fluid.

Equation (1) above is not suited for indicating maximum or minimum values of the dependent variable T_{cc}. If the mixture property to be described passes through maximum or minimum values as the proportions of the components are systematically varied — adding a mixture of hydrocarbon liquid components to natural gas is an example — then a second correlation step usually will be necessary. In addition to an equation like that shown above, use must be made of an equation or of a graphic treatment that will provide for maximum or minimum effects as required.

*"Phase Relations of a Gas-Condensate Fluid at Low Temperature Including the Critical State," by C. K. Eilerts, V. L. Barr, N. B. Mullens and Betty Hanna, Pet. Engr., (Feb., 1948) pp. 154-180, Fig. 11.

It is possible that the authors' correlations can be made to show maximum phase-boundary pressure effects by consideration of additional fluids of lower molal average boiling point. Their Figs. 3 to 16 inclusive in the boiling-point range presently shown indicate that, for given values of "weight average equivalent molecular weight," $\overline{M}_m$, the saturation pressure increases continuously as the "molal average boiling point," B, decreases. If gas were added to fluid without limit to provide mixtures with successively lower molal average boiling points, then, at some boiling point not much lower than the lowest shown in the figures, the curves of saturation pressure should begin to indicate lower and lower pressures as the boiling point was lowered. At the limit, when the mixture is essentially of the composition of the added gas, the saturation pressures indicated may be lower than 2,000 psia.

This result could be obtained whether or not the experiment was conducted in such way as to maintain $\overline{M}_m$ constant. It follows, moreover, that, for a given value of the property T_{cm} as given by Equation (1) above, there may be two restricted compositions and two molal average boiling points.

It is entirely possible that the dew point pressure of gas-condensate fluids of average composition may equal reservoir pressure. The results* of Bureau of Mines tests made at flowing wells show for seven reservoir fluids that the reservoir pressure exceeded the dew point pressure at reservoir temperatures by an average of only 152 psi and in no case by more than 300 psi. The dew-point pressures measured ranged from 2,946 to 4,900 psia and are estimated to be accurate to ±25 psi. Reservoir temperatures ranged from 191° to 251°F. It does not seem likely that this close agreement between reservoir and fluid dew point pressure for seven reservoirs is only coincidental. The original pressure of a gas-condensate reservoir depends on factors associated with the origin, accumulation, and retention of petroleum hydrocarbons, but the reason for the agreement between dew point and reservoir pressures must be latent in substances associated with dew point phenomena; the presence of a liquid phase in the reservoir would be an explanation. Twenty to 30 per cent of the volume of the reservoir pore space could be filled with liquid without appreciable entry of liquid into the well bore during fluid flow, and part of this liquid can be a mixture of hydrocarbons in equilibrium with the reservoir-gas phase. It would, therefore, be expected that the flowing fluid would be the reservoir-gas phase, with a dew point equal to reservoir pressure at reservoir temperature.

GOLDING'S REPLY TO MR. EILERTS

As Eilerts points out, the use of functions of the type (Eilerts' nomenclature)

$$T_{cm} = \frac{N_1 B_1 T_{c1} + N_2 B_2 T_{c2} + \ldots}{N_1 B_1 + N_2 B_2 + \ldots}$$

for direct computation of phase boundary properties is generally unsuitable. These functions may often, however, be used satisfactorily as correlating parameters to help systematize the observed behavior of hydrocarbon systems. Thus, although the functions used in this paper would not serve for direct calculation of maximum or minimum values of phase boundary properties, the combination of these functions as empirical correlating parameters does serve to correlate such properties. The critical loci presented in this paper, for instance, were taken in their final smoothed form from another paper by one of the authors (reference 5 of text) in which the correlation techniques described in the present paper are extended to the direct correlation of the critical temperatures and pressures of complex hydrocarbon mixtures ranging from condensate gases to refinery mixtures. Though no cricondenbar loci are presented in the present paper, the authors feel that visual inspection of Figs. 3 to 16 will reveal the approximate location of such loci with as much accuracy as the presently available experimental information permits.

The present correlation indicates that, at a given temperature and pressure, a single restricted composition (that is, only one set of parameter values) represents all possible saturated fluids. Eilerts speculates that in some cases two restricted compositions may be possible at the same temperature and pressure. If such behavior is indeed found, it would result in an interesting addition to the present correlation. The curves of constant $\overline{M}_m$, as shown in Fig. 2 of the paper would then reach a maximum at some point of lower $\overline{B}$ than their present termination, and turn downwards to lower saturation pressures at still lower values of $\overline{B}$. Extension of the correlation into such regions will, at any rate, have to wait upon publication of additional experimental data.

Eilerts suggests that "if gas were added to fluid without limit . . . then at some boiling point not much lower than the lowest shown in the figures, the curves of saturation pressure should begin to indicate lower and lower pressures . . . " This behavior can actually be followed on the correlation charts if a gas which is itself within the range of the correlation is used. As gas is added to the initial liquid, both $\overline{B}$ and $\overline{M}_m$ decrease, the initial decrease in $\overline{B}$ being relatively the greatest. The corresponding saturation pressures will normally increase initially, reach a maximum pressure, and eventually decrease to the saturation pressure of the gas itself.

Eilerts also suggests that the dew point pressure of gas condensate fields of average composition may be equal to reservoir pressure. It is worth emphasizing that those condensate fields which are not in two phase equilibrium upon discovery are often of especial engineering interest. In particular, condensate reservoirs in which the intial reservoir pressure is above the dewpoint pressure may offer the possibility of increasing the expected economic yield through cycling above the dew point, thus reducing the amount of heavier hydrocarbons lost through retrograde condensation in the reservoir.

The correlation presented in this paper allows an engineer to tell quickly from the well stream analysis and the reservoir temperature and pressure whether a new field is possibly in two phase equilibrium or whether it is definitely a single phase reservoir. It is furthermore often possible to predict the general production behavior of a given reservoir from the relationship between the reservoir temperature and the indicated critical temperature of the particular reservoir material. An estimation of the probable retrograde condensation in gas-condensate fields can often be made from this temperature relationship, for instance. Even more important in some cases is the knowledge of whether a field will produce as a volatile oil reservoir or as a rich condensate reservoir. The sum of this information is often sufficient in itself to permit an engineer to decide whether a given reservoir should be produced by routine techniques or whether further experimental study and economic analysis is warranted. ★ ★ ★

*"Gas Condensate Reservoir Engineering" by C. Kenneth Eilerts, Oil and Gas Jour., (Feb. 8, 1947) pp. 63-68.

The Drift of Things

. . . as followed by **EDWARD H. ROBIE**
Secretary AIME

A Practice That Should Spread

An idea materialized at the recent Annual Meeting that we would like to see extended. Whether held in New York, San Francisco, Los Angeles, Chicago, or St. Louis, a comparatively small proportion of the Student Associates and Junior Members of the Institute are able to attend its Annual Meetings. They can gain a great deal in technical knowledge, in widening their acquaintance, and in absorbing the spirit of a professional society in action by coming to such a meeting, but must perforce be absent because of either the cost or the requirement of their employer or their school that they should remain on the job.

The problem was completely solved for 37 young men last February. A picked group of that number from the School of Mines and Metallurgy at Rolla, Mo., was excused from classes for a week and organized by J. D. Forrester, chairman of the Department of Mining Engineering. The Sinclair Coal Co., Kansas City, Mo., through the good offices of Thomas C. Cheasley, footed the bill of $1,300 for a bus from Rolla to New York and back. Free registration at the meeting was provided by the Institute, and hotel expense was kept nominal by lodging most of the group at Sloan House, the neighboring YMCA, at $1.35 per person per day. We suspect that the AIME Directory 10 years hence will show practically every one of these young men as a member.

Many other companies would doubtless do something similar if the head of the department at a college would promote the idea. Let us have more such trips to the Los Angeles meeting next February.

Junior Members cannot be similarly grouped for attendance at an Annual Meeting, but their employers can offer such a trip with a part, at least, of expenses paid as a prize for conspicuously satisfactory work. From the company standpoint the money would be well invested on several counts. If you, who read this, happen to be the head of a company or local operation, why not announce now that one or more of your Junior Members will have the opportunity to go to the Los Angeles meeting? Alert Junior Members will doubtless find a way of bringing this suggestion to the attention of their boss.

Petroleum Branch Affairs

. . . as interpreted by **JOE B. ALFORD**
Executive Secretary, Petroleum Branch

MEMBERSHIP REINSTATEMENT

Several major changes have been made recently in the regulations pertaining to membership reinstatement, and the rules on reinstatement in all grades of membership are reviewed below to acquaint you with them. Former members are a good source of new members, in that they frequently seek reinstatement. Often a gentle "assist" from a member is all they need to take the step. The following will be a guide for you in advising those who desire reinstatement.

Former Member or Associate—Reinstatement to Member or Associate

Resigned: If the former member resigned in good standing when he terminated his membership, he must pay *only* the current dues, or a total of $20. If he reinstates after June 1 of any given year, he pays only one-half year's dues, for the balance of that year, or a total of $10.

Suspended: If the former member let his membership lapse and was suspended for non-payment of dues, but is in good standing otherwise, he must pay the current dues plus a maximum of $20 dues in arrears, or a total of $40. If he reinstates after June 1 of any given year, he pays one-half of the current dues, or a total of $30.

Former Junior Member—Reinstatement to Member or Associate

In this case the member either resigned or was suspended while he was still a Junior Member, so he had not paid the initiation fee. His arrears, if any, will be canceled, but to be reinstated he must pay the current dues plus the initiation fee, or a total of $40. If he reinstates after June 1, it is one-half year dues, or a total of $30.

Former Student Associates—Reinstatement to Higher Grade

Student Associates are suspended from the rolls at the end of the calendar year in which they are graduated, so no arrearage in dues is built up. To be reinstated as a Junior Member, a former Student Associate simply pays the current year's dues of $12. To be reinstated as a Member or Associate, he pays current dues and the initiation fee in the same way as former Junior Members.

General Information

Application for Reinstatement: Should be initiated by the completion and submission of a standard application blank for membership. The Admissions Committee must have the information requested on the blank to reinstate a member.

Installment Payment of Initiation Fee: The initiation fee can be paid in four annual installments of $5 each at the time of paying annual dues. No new initiation fee is required from those who have already paid one. The installment provision permits reinstatement for only $25, or $15 for the last half of the year if a member resigned in good standing.

Restoration of Original Election Date: Reinstatement will normally establish the election date as the date of reinstatement. For a former member to restore his original election date he must pay all of the dues he has in arrears. If extenuating circumstances existed to cause a member to let his membership lapse, the Board of Directors will consider restoring the original election date without payment of the entire arrearage upon a statement of the special circumstances in the case.

Change of Status of Student Associates to Higher Grade: New regulations require that the Student Associate must submit an application blank for a change to higher grade, but it may be endorsed only by his original Member endorser (faculty member) plus one new endorser. If his original endorser for Student Associate membership is not available, the application must be endorsed by three endorsers in the usual manner. Another new regulation permits a credit of $2 on the initiation fee for each year that a Student Associate or Junior Member has been continuously on the rolls. ★ ★ ★

Petroleum Branch Affairs

. . . as interpreted by JESS E. ADKINS
Editor, Journal of Petroleum Technology

At the open meeting of the Petroleum Branch Executive Committee in New York Feb. 20, a number of important items were discussed and reported upon by committeemen. Paul R. Turnbull took over the chairmanship of the Executive Committee for 1952 from Richard W. French. Other officers present were D. V. Carter, newly appointed member replacing John R. McMillan, elected vice-chairman of the Branch for 1952, John S. Bell, R. C. Earlougher, T. C. Frick, Morris Muskat, W. E. Stiles, E. N. Van Duzee and G. L. Yates.

Membership Increase Reported

Jack H. Beesley, chairman of the Membership Committee, reported that his committee had a successful year. Main event was the membership contest conducted in 1951 between Local Sections and Chapters. The contest was based on the greatest number of applications for all grades of membership except Student Associates sent in by each Section and upon percentage increases over their membership as of Aug. 10, 1951. A total of 192 new applications were received during the drive which lasted from Sept. 1 through Dec. 31. The Southwest Texas Section took first place in the drive with 37 new applications, representing a 12.8 per cent increase in the Section's membership.

The Branch had the following number of members who were elected and accepted during 1951:

New Members, Associates, Juniors	344
Change of Status to Member and Associate	62
Change of Status to Junior Member	65
Total	471

Publications Committee

J. M. Bugbee, 1951 chairman of the Publications Committee, could not be present at the meeting and Secretary Joe B. Alford reported that the committee handled 140 papers during the year with disposition as follows:

Carried over from 1950	65	
Submitted during 1951	75	
Submitted during 1951	75	140
Published as Technical Papers in 1951	45	
Published as Articles	17	
Published as Technical Notes	7	
Declined	16	
Withdrawn	6	
Carried over to 1952	49	140

Local Section Revolving Fund

In October, 1951, the Oklahoma City Local Section presented the Branch with a $1,000 check for establishment of a revolving fund to be used by each host Section for the Fall Meetings of the Branch. The intent of the Section is for the fund to be used as a pre-meeting capital fund and as a reserve in the event of financial loss.

Lincoln F. Elkins reported that the $1,000 represented a surplus from the 1951 Fall Meeting held in Oklahoma City. The Executive Committee gave the matter extended discussion and invited comments from the floor. Among the suggestions offered was one which recommended submitting the idea to all Local Sections for their reactions. This was voted by the Committee and the idea will be submitted to Local Sections for acceptance or rejection.

Status of "Local" Members

The question has arisen as to whether the Branch should adopt regulations governing "local" members in Chapters and Local Sections. Data were presented on the percentage of "local" members in various Local Sections and the reaction of these local units to the suggestion that the tenure of "local" members be limited. The discussion which followed made it apparent that the majority of members felt that no regulations should be established. It was pointed out that Local Sections and Chapters should be essentially self-governing autonomous units and that "local" members are an asset in several ways. The consensus was that local units should be permitted to handle "local" membership on any basis they desire.

It was explained, however, that the distinction should always be made that "local" members are not AIME members. A member of a Local Section or Chapter is affiliated only with that particular unit and is not a member of the Institute.

Establishing a New Unit of Permeability

Morris Muskat reported that the Section Committee of the American Standards Association had endeavored to establish an absolute unit of permeability using consistent absolute units throughout. Previously, Muskat had recommended that such a unit of permeability should not carry the name "darcy" because of already established meaning of the term in the industry. In the discussion following, it was apparent that there was unanimous feeling that present terminology and application of the term in the industry should not be disturbed. It was so voted by the Committee.

Branch Policy on Social Functions

Some unfavorable comment has been received from members on stag affairs as part of Fall Meetings. H. M. Cooley and Secretary Alford were instructed to draft a revision of the original statement of policy concerning the matter and have it ready for consideration at the next meeting of the Committee at the 1952 Fall Meeting in Houston. John S. Bell stated that the Committee should draft specific requirements concerning social functions.

Assistance to Local Sections and Chapters

It was reported that several Chapters had made requests for financial assistance from the Branch. Secretary Alford recommended that the Branch continue to support Branch Chapters financially until they are able to stand on their own feet. John E. Sherborne pointed out that this was not consistent with current feelings that units should be self supporting and that the assistance financially should be specifically limited to an interim period. It was voted that $300 be sent to the Pacific Petroleum Chapter and $100 each be sent to the Illinois Basin and Wyoming Chapters and the South Plains Sub-Section.

A Standing Committee on Student Activities

It was pointed out that there is an apparent gap in Branch activities pertaining to student activities. Secretary Alford recommended that a Standing Committee on Student Activities be established and be concerned with all phases of student chapter work, student associate membership and the coordination of Branch activities with them. This idea was voted into effect by the Committee.

Petroleum Conservation Volume

Upon the recommendation of the secretary, it was voted that the Branch give a complimentary copy of the Doherty Memorial volume, *Petroleum Conservation*, to the petroleum engineering libraries of all colleges and universities in the United States teaching petroleum engineering. ★ ★ ★

Education for Engineering

Continued from Page 15, Section 1

the emotional. All have their place. History is, in the main, the study of group reactions in the past to various stimuli, mainly economic. Politics is the study of history in the making. Economics is the study of wealth, defined as the means of satisfying man's material desires. Literature, in the sense of an organized study, comprises the reactions of individual authors to the conditions of man's life; expressed analytically and critically in essay form, or synthetically and emotionally as fiction.

From the standpoint of the engineering curriculum these humanistic studies may be classified as utilitarian and cultural. History, politics and economics go into the utilitarian class. They should be supplemented by brief courses in business practices and business law. Literature is in the cultural group. In my view, it should be supplemented by introductory courses in astronomy, geology and biology to open the student's eyes, respectively, to the universe, the earth, and the make-up of the living matter that surrounds him.

Communication is of the essence of direction. An engineer's orders and reports, both outgoing and incoming, are sequences of words. They must be understood, if the desired results are to follow. This requires command of the prevailing language.

Command of this kind connotes a vocabulary large enough to comprehend all of the physical objects, actions and emotions with which the engineer must deal: accurate knowledge of the customary rules of grammar and simple rhetoric — without, perhaps, the ability to quote any of them; understanding of subject matter; and, outgoing, something to say.

All instructors should make language one of their grading bases. Vocabulary grows with knowledge; knowledge of grammatical usages and simple sentence structure with criticised practice; understanding of subject matter with academic progress; and something to say follows.

Opportunities in Engineering

Continued from Page 17, Section 1

such positions during an emergency. Two factors enter the situation. The first is that engineers who have been so employed for any considerable length of time probably now lack knowledge of the skills and techniques essential in the fields of design, development, and mechanical or chemical production, where our greatest needs exist. The second factor is that engineers who are non-essential in their present positions, whatever they may be, will probably be drained off into more essential engineering activities as the demand for their services makes itself felt. However, industry is urged to take all possible steps through upgrading of present engineers, shortening the period of training for new men, etc., to make maximum utilization of present personnel.

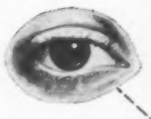
Provision of an adequate future supply of engineers constitutes an entirely different problem. The present shortage is so deep, and the prospective long range demand so great, that the attack upon this problem must be fundamental. The first requisite is to supply to our boys, and to a certain extent to our girls too, the incentive and the desire to undertake an engineering career. To accomplish this we must take steps to develop a more widespread knowledge of what the engineer does and of the importance of the engineering profession to the American way of life. America's high standard of living is due to its productivity. Here 6 per cent of the world's population produces 50 per cent of the world's goods. In this accomplishment the engineer's role is outstanding.

Outlets for the skill of the individual engineer are varied. The scientist and the engineer cooperate in research and development. Design of buildings, machines, equipment and installations of all sorts is the engineer's primary function. It is entirely logical however that the engineer finds his place in the fields of production, sales or service. Many an industrial establishment, particularly those engaged in the production of machinery or mechanical equipment, feels that most of its major activities should be headed by engineers. Engineers have unusual opportunities to rise to the positions of top management in industry as is so clearly evidenced by the numbers who have done so. The military services and the civilian branches of government offer many opportunities.

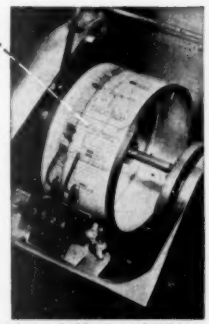
The great increase in labor rates in the past few years has made continued advance in mechanization essential to survival in a competitive system. As manufactured articles come within reach of more and more people, sales and employment have increased. New discoveries and inventions increase rapidly, and their demands upon the scientist and engineer are exceptional.

It is this expanding economy of ever-increasing productivity that is America's pride and America's hope for the future. Within the life span of many of us the normal work week has been almost cut in half considering the hours of work, vacations, holidays and the like. The back-breaking tasks have been largely absorbed by mechanization. For much of this the engineer is responsible. He should aspire to preserve this way of life through which the material comforts and conveniences provided by a system of free enterprise may be made available to more and more of the world's people. In such a world the engineering profession will face challenge — and opportunity — as never before.

SEE formation changes *as you drill* WITH GEOLOGRAPH



With Geolograph, you actually watch the drilling change as the bit bites into contrasting strata — foot by foot! You'll find that this subsurface control, while drilling, results in a higher percentage of successful drill stem tests; fewer and more correctly placed cores; accurate determination of net pay thickness and elimination of many depth corrections!



Abilene, Houston, Odessa, Lubbock and Wichita Falls, Texas - Bakersfield, Calif. - Shreveport and Baton Rouge, La. - Casper, Wyo. - Oklahoma City, Okla.

TIME WILL TELL

THE GEOLOGRAPH CO. INC.

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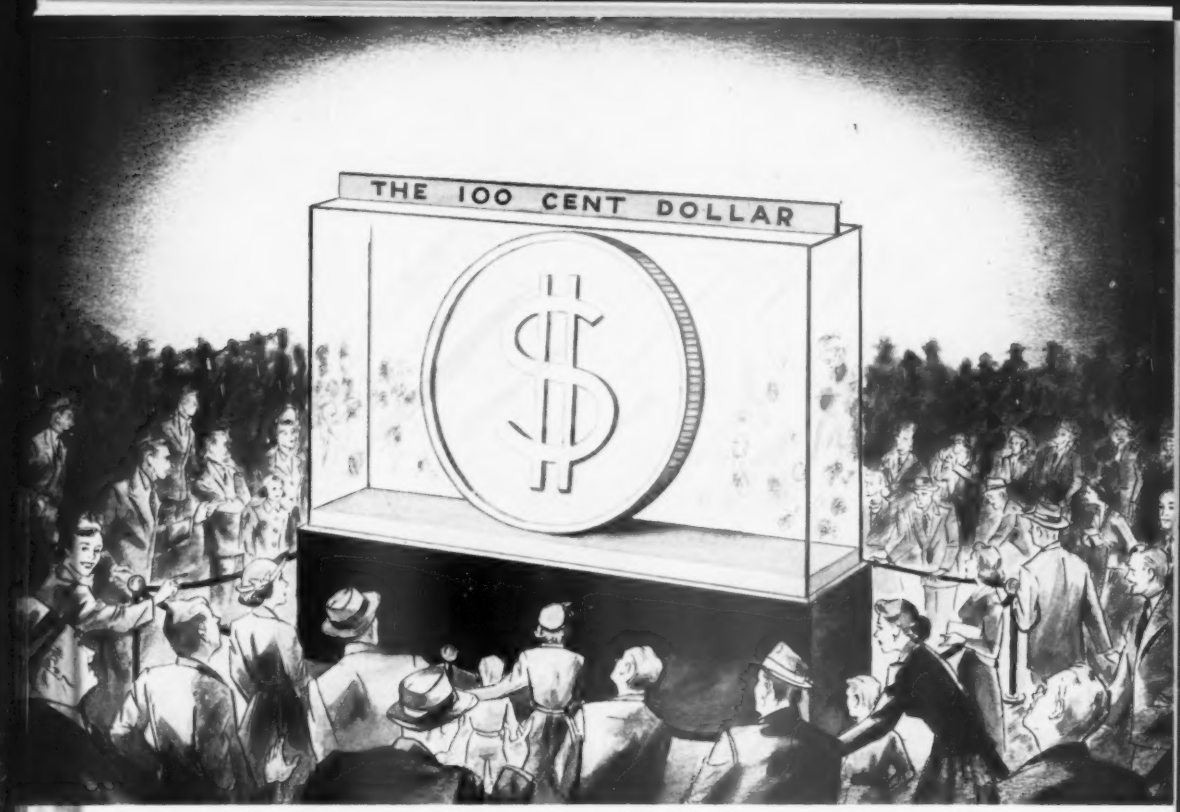

Who Says the 100 Cent Dollar Is a Museum Piece?

. . . Actually, the American Dollar buys *more* in Halliburton cementing service today than it did in 1924!

Erle P. Halliburton

Chairman of the Company
HALLIBURTON OIL WELL CEMENTING CO.
Duncan, Oklahoma

Personals

E. G. "Ty" Dahlgren, oil and gas consultant, has opened new offices in the Hales Building, Oklahoma City. A graduate of the University of Wisconsin in geology, Dahlgren was associated with the Oklahoma City Producers Association and the Oklahoma Corporation Commission for several years. From 1937 to 1939 he was with the Kansas Corporation Commission. He has also served with the Oil and Gas Unit of the Securities and Exchange Commission and the Production Division of PAD in Washington, D. C., and with the Interstate Oil Compact Commission, in charge of technical activities.

+

W. M. Capps has been transferred from Tulsa to the Big Lake, Texas, District of the Amerada Petroleum Corp. With the same company, J. R. Enloe, Jr., has been transferred from Tulsa to Tatum, N. M., and O. C. McBryde, Jr., formerly in Monument, N. M., is now in Tulsa.

+

William W. Charles, Jr., has become chief geologist for Central Leduc Oils, Ltd., of Calgary, Alberta, and will be located in Los Angeles, Calif. He was formerly district geologist for Pacific Western Oil Corp., in Bakersfield, Calif.

L. V. Nugent was recently added to the firm of Kirkpatrick and McGuire, consulting petroleum engineers in Shreveport, La. Nugent will be located in Chanute, Kans., as field superintendent of the company's water-flooding projects.

+

George Hetherington, Jr. recently accepted a position with the Gulf Oil Corp., Pittsburgh, as a staff reservoir engineer.

W. A. Schaeffer, Jr., is chief engineer for the Southern Production Co., Inc., in Fort Worth, Tex. It was erroneously reported in the April issue that Schaeffer was consulting petroleum engineer for the firm.

+

Earnest B. Granville is now assistant drilling and production superintendent for Fain and McGaha, Wichita Falls, Texas.

Reinartz Nominated For President-Elect

The Nominating Committee for Institute Officers in 1953, John R. Suman, chairman, completed its work at the Annual Meeting in February, and has made its report to the Board of Directors. The President-elect in 1953 serves as President in 1954. The ticket follows:

For President-elect and Director — Leo F. Reinartz.

For Vice-President and Director — A. B. Kinzel and Lloyd E. Elkins.

For Director — Hjalmar W. Johnson, Philip Kraft, Gail Moulton, Edwin L. Oliver, Philip Wilson, and Elmer Isern.

Reinartz is a vice-president of the Armco Steel Corp., Middletown, Ohio.

As required by the bylaws, brief biographical sketches of the nominees will be published in the July issue of the Journal of Petroleum Technology.

Another Hycalogged Well
fully evaluated ... in less time
HYCALOG
THE HYCALOG COMPANY
SHREVEPORT, LA.
"TIME BREAKDOWN FOR DRILLING OPERATIONS
DEPTH: From 5550' To 13,539'
FIELD Wildcat
"Time Breakdown Covers Only the Period a Hycalog Unit was Logging the Well.
DRILLING OPERATIONS | TIME IN HOURS | PER CENT OF TOTAL
DRILLING 950.65 54.60
CORING 10.77 .62
TRIPS NEW BIT 393.00 22.57
TRIPS NEW CORE BIT 28.37 1.63
RIG REPAIR 128.93 7.41
CIRCULATING OUT SAMPLES 99.43 5.71
CONDITION HOLE 38.85 2.23
REAMING 3.90 .22
DRILL STEM TEST 47.25 2.71
SET PIPE None None
WAITING ON ORDERS 15.27 .88
FISHING None None
STRAIGHT HOLE TEST 2.00 .12
ELECTRIC LOG 14.58 .84
WAITING ON CASING 8.00 .46
TOTALS 1741.00 100.00
This record of a real well is one of hundreds in our files which show how Hycalogging saves you valuable drilling time.
TEXAS
Midland
Corpus Christi
San Antonio
LAFAYETTE, LOUISIANA
MEXICO CITY, MEXICO
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HYCALOGGING is continuous hydrocarbon logging of cuttings and mud samples with on-location analysis of recovered cores.
WELL LOGGING . . . DIAMOND CORING . . . CORE ANALYSIS
HYCALOG COMPANY

Employment Notices

The JOURNAL will post notices of men and jobs available. Companies and AIME members are invited to use this space, for which there is no charge. Except as noted below, address replies to: Code (appropriate number), JOURNAL OF PETROLEUM TECHNOLOGY, 408 Trinity Universal Bldg., Dallas 1. Show return address on envelope. These replies will be forwarded unopened and no fees are involved.

Replies to the positions coded M-682, Y6685, Y6653, and Y6296, below should be addressed to: Engineering Societies Personnel Service, 8 West 40th St., New York 18, N. Y. The ESPS, on whose behalf these notices are published here, collects a fee from applicants actually placed.

PERSONNEL

♦ Petroleum engineer with two years' experience in production and drilling desires employment as reservoir engineer. Have some graduate work in reservoir engineering. Presently employed with major oil company; would be available in 30 days. Thirty years of age. Prefer employment in East Texas-Arkansas-Louisiana area. All offers acknowledged. Code 163.

♦ Geologist-petrographer. Experienced in subsurface geology and petrographic rock and mineral identification. Desires position as either geologist or petrographer. M-682.

POSITIONS

♦ Instructor or assistant professor, 25-30, with a few years' practical experience in petroleum production engineering. Should be American citizen. Salary up to $5,000 a year depending on experience. Location, West. Y6685.

♦ Petroleum geologists, experienced, for subsurface study. Should have three to five years' experience in geological work. Location, Texas. Y6653.

RESERVOIR ENGINEERS

Major oil company with extensive operations in the Middle East has openings in its New York office for qualified petroleum or reservoir engineers, proficient in mathematics, and with extensive experience in oil and gas reservoir engineering on primary and secondary recovery problems. Salary: Open.

Send complete resume to:
Code 540-A
Journal of Petroleum Technology
408 Trinity Universal Bldg.
Dallas 1, Texas

♦ Mechanical engineer, designer, with two to five years' experience in design and layout for oil refinery. Salary, $6,000 a year. Location, New York, N. Y. Y6296.

♦ The Department of Petroleum Engineering, Louisiana Polytechnic Institute, Ruston, La., is seeking a full-time (nine months) staff member for undergraduate instructional duties. Occasional summer teaching possible. MS degree in petroleum engineering prerequisite. Broad geological background desired. Rank and salary dependent upon qualifications and experience. Write direct to above address. ★ ★ ★

Proposed for Membership, Petroleum Branch

Total AIME membership on Feb. 29, 1952, was 17,221; in addition, 2,341 Student Associates were enrolled.

ADMISSIONS COMMITTEE

T. D. Jones, chairman; Thomas G. Moore, vice-chairman; H. S. Bell, F. W. Hanson, R. H. Chadwick, T. W. Nelson, C. A. R. Lambly, John T. Sherman, A. C. Brinker, G. P. Lutjen, Ivan Given, E. A. Prentis, C. Leslie Rice and J. H. Scaff.

Institute members are urged to review this list as soon as the issue is received and immediately to wire the Secretary's office, night message collect, if objection is offered to the admission of any applicant. Details of the objection should follow by air mail. The Institute desires to extend privileges, but does not desire to admit persons unless they are qualified. Objections on applications should be received on the 15th of the month following publication of PETROLEUM TECHNOLOGY.

In the following list C/S means change of status; R, reinstatement; M, member; J, Junior Member; A, Associate Member; S, Student Associate; F, Junior Foreign Affiliate.

CALIFORNIA
Compton — Fyle, Delbert E. (C/S-S-J).
Culver City — Johnson, Thomas A., Jr. (R, C/S-S-J).
Lafayette—Somerton, Wilbur H. (C/S-A-M).
Los Angeles — Allen, William J. (M); Davis, Clyde R. (C/S-S-J); Patterson, Samuel A. (C/S-A-M); Welbourn, Marshall E. (C/S-S-J).
Orcutt — Bickmore, David K. (C/S, Auto A-M).
Taft — Evans, Barry L. (R, C/S-S-J).

ILLINOIS
Centralia — Hughes, James D. (J).

KANSAS
Russell — Reggin, Walter A. (C/S-S-J).

KENTUCKY
Ashland — Lang, William E. (M).

LOUISIANA
Abbeville — Ellis, David W. (R, C/S-S-J).

NEW JERSEY
Jersey City — Caponegro, Frank (A).

NEW MEXICO
Monument — Brewer, Ross A., Jr. (J).

NEW YORK
Freeport, L. I. — Morford, Bud W. (M).
Yonkers — Walsh, Thomas E. (R, C/S-S-J).

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VENEZUELA
Maracaibo — Blendermann, Gene R. (C/S-S-J); Chavez, Buenaventura (J); Gordillo, Carlos A. (J). ★ ★ ★

Members Urged to Return Directory Listing Cards

Last month, reply postal cards were sent to all AIME members asking for information for listing their names in the 1952 Directory, to be issued late in the year. Members are urged to return the cards as promptly as possible, with information as to their company connection and address.

If cards are not returned, the address to which the cards are mailed, and which is given in the upper right-hand corner of the reply card, will be used in the Directory. This is the address to which AIME publications are now sent. In many instances it is the member's home address, whereas the address and position given in the Directory is customarily the company or office address.

All records are being transferred to the Flexoprint system, which takes some months to complete. When completed, a Directory can be printed on short notice at any time.

Members who have not returned the card should do so now. If, by chance, you did not receive one, please write and ask for one. Advise headquarters immediately if you change your position or address, giving both the address you wish used for publications (if it is being changed) and the listing you wish in the Directory. ★ ★ ★

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Book Reviews

The following books are available in the Engineering Societies Library, and may be borrowed by mail by AIME members for a small handling charge. The library also prepares bibliographies and translations, and provides search, photostat and microfilm services. Address inquiries to Ralph H. Phelps, Director, Engineering Societies Library, 29 West 39th St., New York 18, N. Y.

Reviews of Petroleum Technology

George Sell, editor. Volume II (covering 1949). Institute of Petroleum, Manson House, 26 Portland Place, London, W.1, England, 1951. 280, XXIV p., tables, 9¼ x 6¼ in., bound. 27s6d.

The subjects covered in this extensive literature survey are as follows: petroleum geology, geophysics, drilling and production, chemical and physical refining, cracking and other processes, plant instrumentation, chemistry and physics of petroleum, analysis and testing, crude oils, petroleum gases, gasoline, fuel and insulating oils, bitumen, synthetic fuels, statistics. Some 3,000 literature references are given along with the respective chapters. There is an alphabetical name index to the literature references.

Progress in Petroleum Technology

(Advances in Chemistry Series No. 5)

Edited by the staff of Industrial and Engineering Chemistry. American Chemical Society, Washington, D. C., 1951. 392 pp., illus., diagr., tables, charts, 9¼ x 6 in., paper. $3.00.

A collection of some thirty papers presented at the Symposium on Twenty-Five Years of Progress in Petroleum Technology, held by the Division of Petroleum Chemistry of the American Chemical Society in 1951. The papers deal with such subjects as catalytic cracking, synthesis of liquid fuels from natural gas, liquid fuels from coal and oil shale, dewaxing and deasphalting, motor fuels, tetraethyllead, lubricants, fuel oil, petroleum, coke and coking, elastomers and plastics, and synthetic detergents from petroleum.

Theoretical Petrology

By Tom F. W. Barth. John Wiley & Sons, Inc., New York, 1952. 387 pp., diagr., charts, tables, 9¼ x 6 in., cloth. $6.50.

A scientific study of the genesis of rocks and their mode of development, this book deals with all fields of petrology — covering igneous, sedimentary and metamorphic rocks. Quantitative laws of physics and chemistry are applied to geological problems. The origin, evolution, transfiguration, destruction, and redevelopment of the rock masses of the earth's crust are discussed.

Fluid Flow in Pipes

By Clifford H. McClain. The Industrial Press, New York, 1952. 123 pp., tables, charts, diagr., 9¼ x 6 in., bound. $3.00.

A summary of modern theory in the flow of liquids and gases through piping and ducts. The book deals in a concise, simple manner with viscosity, friction, turbulence, steam-line flow, head, and other factors which influence the overall result. Dimensional relationships are emphasized. Practical applications and detailed worked-out examples help to clarify the handling of piping problems.

Essentials in Problem Solving

By Zuce Kogan. 1951. 79 pp., 8½ x 5½ in., paper. From the author, 724 Sheridan Road, Chicago 13, Illinois. $3.00.

The author discusses and gives practical examples of problem solving in which the specific problem is related to a generalized class of problem characteristics for which there is a generalized solution. From this the specific solution is then derived.

Advertisers' Index

	Page
A-1 Bit & Tool Co. — *Calvin L. Clausel, Jr., Houston*	*
Axelson Manufacturing Co. — *Heintz & Co., Los Angeles, Calif.*	*
Baash-Ross Tool Co. — *Dozier-Eastman & Co., Los Angeles, Calif.*	*
Baroid Sales Division — *Darwin H. Clark Co., Los Angeles*	Sec. 1—22
Baker Oil Tools, Inc. — *Theo. M. Martin Co., San Gabriel, Calif.*	Sec. 1—8, 9
Barret, William M., Inc. — *Bozell & Jacobs, Shreveport, La.*	*
Black, Sivalls & Bryson, Inc. — *R. J. Potts-Calkins & Holden Adv., Kansas City, Mo.*	*
B and W Incorporated — *Lester C. Nielson Co., Huntington Park, Calif.*	Sec. 1—5
Clark Bros. Co., Inc. — *Harold Warner Co., Buffalo, N. Y.*	Sec. 1—6, 7
Cooper-Bessemer Corp. — *Griswold-Eshleman Co., Cleveland, Ohio*	*
Core Laboratories, Inc. — *Duvall Williams, Dallas, Tex.*	Sec. 1—4
Dale Company — *Lester C. Nielson Co., Huntington Park, Calif.*	*
Dowell Incorporated — *MacManus, John & Adams, Inc., Detroit, Mich.*	Sec. 1—10
Eastman Oil Well Survey Co. — *Ted Workman Advertising, Dallas, Tex.*	*
Farrand Optical Co. — *Firestone Advertising Agency, New York, N. Y.*	Sec. 1—18
Garrett Oil Tools, Inc. — *W. L. Culver, Houston, Tex.*	Sec. 1—28
Geograph Co., Inc. — *Lowe Runkle Co., Oklahoma City, Okla.*	Sec. 2—3
Halliburton Oil Well Cementing Co. — *Hill & Christopher, Los Angeles, Calif. Bachrodt, Newell, O'Kane and Gano, Chicago, Ill.*	Sec. 1—2. Sec. 2—4, Third Cover
Hycalog Co. — *Glenn Mason Advertising, Shreveport, La.*	Sec. 2—5
Infilco, Inc. — *Ruthrauff & Ryan, Hollywood, Calif.*	*
Johnston Testers — *Wallace Davis & Co., Houston, Tex.*	Sec. 1—12
Keystone Development Corp. — *Brennan Advertising Agency, Houston, Tex.*	*
Lane-Wells Co. — *Darwin H. Clark Co., Los Angeles, Calif.*	Fourth Cover
Larkin and Co. — *Peter Baycura Adv., Butler, Penn.*	*
Lufkin Foundry & Machine Co. — *Cudlipp Advertising Agency, Lufkin, Tex.*	Sec. 1—16
Magnet Cove Barium Corp. — *Rives, Dyke and Co., Houston, Texas*	*
McCullough Tool Co. — *R. P. Casterline Advertising, Los Angeles, Calif.*	*
Lee C. Moore Corp. — *Watts, Payne Advertising, Tulsa, Okla.*	*
Oil Base, Inc. — *Dozier-Eastman & Co., Los Angeles, Calif.*	Sec. 1—1
Otis Pressure Control, Inc. — *Dan Goodrich, Dallas, Tex.*	*
Pelton Water Wheel Co. — *Edward A. Stratman Adv., Huntington Park, Calif.*	*
Professional Services	Sec. 2—7
Schlumberger Well Surveying Corp. — *Rives, Dyke & Co., Houston, Tex.*	Second Cover
The Second National Bank, Houston, Tex. — *Gano, Bachrodt, Edwards, Inc., Houston, Tex.*	Sec. 1—27
Sperry-Sun Well Surveying Co. — *Wallace Davis & Co., Houston*	*
United Geophysical Co., Inc. — *Dozier-Eastman & Co., Los Angeles, Calif.*	*
Well Surveys, Inc. — *Watts, Payne Advertising, Tulsa, Okla.*	*
Zublin Flexible Drill Pipe — *Roy F. Irvin Advertising, Los Angeles, Calif.*	*

* In previous issues

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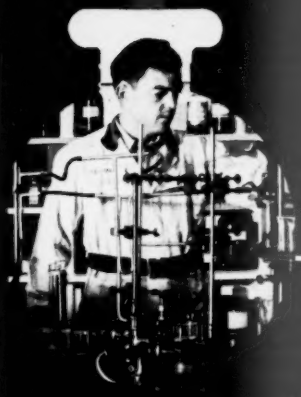

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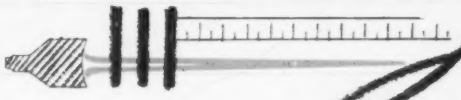

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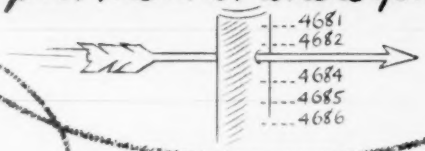

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